

ZOOM OPTICAL SYSTEM AND  
ELECTRONIC SYSTEM INCORPORATING IT

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## TECHNICAL ART

The present invention relates generally to a zoom optical system and an electronic system incorporating it, and more particularly to a compact zoom optical system and an electronic system incorporating it. This electronic system, for instance, includes digital cameras, video cameras, digital video units, personal computers, mobile computers, cellular phones and personal digital assistants.

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## BACKGROUND ART

Recently, personal digital assistants acronymed as PDAs and cellular phones have undergone explosive growth in demand. Some such systems have digital camera or digital video functions added to them. To implement these functions, CCD (charge coupled device) or CMOS (complementary metal oxide semiconductor) sensors are now used as image pickup devices. To reduce the sizes of such systems, it is preferable to use an image pickup device having a relatively small light receiving area. In this case, a sensible tradeoff between size reductions and cost savings must be made while the performance of an optical system is kept high. Size reductions are now achieved by reducing the number of lenses used. On the other hand,

cost reductions by use of a fewer step, for instance, is now achieved by use of a fabrication process wherein lenses are formed under pressure in a lens holder.

For reductions in the number of lenses that form an optical system, it is necessary to use aspheric lenses. For the fabrication of such aspheric lenses, use is generally made of a fabrication process wherein a preform is pressed in a state softened by heating (hereinafter called the prior art lens processing). With this prior art lens processing, an aspheric lens is formed larger than the required outer diameter, and rounding is carried out in such a way as to incorporate it in a lens barrel. For this reason, for instance, the thickness of the outer periphery of the lens at the necessary outer diameter will become larger than that of the lens during rounding. A reduction in the number of lenses for compactness will result in an increase in lens thickness, because the refracting power of each of lenses inclusive of a positive lens will become strong. For this reason and to give the lens a sufficient peripheral thickness, the peripheral thickness of the lens at the necessary outer diameter will become far larger. Thus, no sufficient effect on size reductions will still be obtained.

On the other hand, Patent Publication 1 says nothing about not only size reductions but also conditions for size reductions.

Patent Publication 1

SUMMARY OF THE INVENTION

Such being the prior art situations, the primary  
5 object of the invention is to provide a zoom optical  
system that can offer an effective tradeoff between cost  
reductions and size reductions, and an electronic system  
incorporating it.

According to the first aspect of the invention,  
10 there is provided a zoom optical system comprising a lens  
group having negative refracting power and a lens group  
having positive refracting power, characterized in that at  
least one lens is formed by molding of a first lens blank  
that provides a surface including at least an optical  
15 function surface after molding, and a second lens blank  
that provides a surface other than said surface including  
at least an optical function surface after molding,  
wherein the first lens blank and the second lens blank are  
integrated into a one-piece lens.

20 In one preferable embodiment of the invention, the  
second lens blank is characterized by having shading  
capability.

In another preferable embodiment of the invention,  
the second lens blank is characterized by being a metal,  
25 cermet or ceramics.

Yet another embodiment of the invention is  
characterized in that an organic-inorganic composite lens  
blank is used as an optical lens blank for at least one

optical element that forms a part of the optical system.

Further, the invention includes an electronic system comprising the above zoom optical system and an electronic image pickup device located on an image side thereof.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is generally illustrative of how to fabricate the one-piece lens for use with the invention. Fig. 1(a) is illustrative of how a lens blank is located before lens  
10 molding, and Fig. 1(b) is illustrative of how the lens blank is molded into the one-piece lens after lens molding.

Fig. 2 is a perspective view of the one-piece lens molded by the fabrication process of Fig. 1.

Fig. 3 is generally illustrative of another  
15 fabrication process of the one-piece lens for use with the zoom optical system. Fig. 3(a) is illustrative of how lens blanks are located before lens molding, and Fig. 3(b) is illustrative of how the lens blanks are molded into the one-piece lenses after lens molding.

20 Fig. 4 is illustrative in perspective of a one-piece lens fabricated by the fabrication process of Fig. 2.

Fig. 5 is generally illustrative of yet another fabrication process of the one-piece lens for use with the zoom optical system. Fig. 5(a) is illustrative of how  
25 lens blanks are located before lens molding, and Fig. 5(b) is illustrative of how the lens blanks are molded into the one-piece lenses after lens molding.

Fig. 6 is illustrative in perspective of a one-piece



lens fabricated by the fabrication process of Fig. 5.

Fig. 7 is illustrative in lens section of Example 1-1 of the first zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 8 is illustrative in lens section of Example 1-2 of the first zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 9 is an aberration diagram for Example 1-1 of the first zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 10 is an aberration diagram for Example 1-2 of the first zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 11 is illustrative in section of one exemplary one-piece lens used in Example 1-1 of the first zoom optical system.

Fig. 12 is illustrative in section of one exemplary one-piece lens used in Example 1-2 of the first zoom optical system.

Fig. 13 is illustrative in section of another

exemplary one-piece lens used in Example 1-2 of the first zoom optical system.

Fig. 14 is illustrative in lens section for Example 2-1 of the second zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 15 is illustrative in lens section for Example 2-2 of the second zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 16 is an aberration diagram for Example 2-1 of the second zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 17 is an aberration diagram for Example 2-2 of the second zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 18 is illustrative in section of one exemplary one-piece lens used in Example 2-1 of the second zoom optical system.

Fig. 19 is illustrative in section of one exemplary one-piece lens used in Example 2-2 of the second zoom optical system.

Fig. 20 is illustrative in lens section of Example 3-1 of the third zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an  
5 infinite object point.

Fig. 21 is illustrative in lens section of Example 3-2 of the third zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an  
10 infinite object point.

Fig. 22 is an aberration diagram for Example 3-1 of the third zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object  
15 point.

Fig. 23 is an aberration diagram for Example 3-2 of the third zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object  
20 point.

Fig. 24 is illustrative in section of one exemplary one-piece lens used in Example 3-1 of the third zoom optical system.

Fig. 25 is illustrative in section of one exemplary  
25 one-piece lens used in Example 3-2 of the third zoom optical system.

Fig. 26 is illustrative in lens section of Example 4-1 of the fourth zoom optical system, showing lens

sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 27 is illustrative in lens section of Example 4-2 of the fourth zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 28 is an aberration diagram for Example 4-1 of the fourth zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 29 is an aberration diagram for Example 4-2 of the fourth zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 30 is illustrative in section of one exemplary one-piece lens used in Example 4-1 of the fourth zoom optical system.

Fig. 31 is illustrative in section of one exemplary one-piece lens used in Example 4-2 of the fourth zoom optical system.

Fig. 32 is illustrative in lens section of Example 5-1 of the fifth zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an

infinite object point.

Fig. 33 is illustrative in lens section of Example 5-2 of the fifth zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate  
5 setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 34 is an aberration diagram for Example 5-1 of the fifth zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at  
10 a telephoto end (c) upon focusing on an infinite object point.

Fig. 35 is an aberration diagram for Example 5-2 of the fifth zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at  
15 a telephoto end (c) upon focusing on an infinite object point.

Fig. 36 is illustrative in section of one exemplary one-piece lens used in Example 5-1 of the fifth zoom optical system.

20 Fig. 37 is illustrative in section of one exemplary one-piece lens used in Example 5-2 of the fifth zoom optical system.

Fig. 38 is illustrative in lens section of Example 6-1 of the sixth zoom optical system, showing lens  
25 sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 39 is illustrative in lens section of Example

6-2 of the sixth zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

5            Fig. 40 is illustrative in lens section of Example 6-3 of the sixth zoom optical system; showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

10           Fig. 41 is an aberration diagram for Example 6-1 of the sixth zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

15           Fig. 42 is an aberration diagram for Example 6-2 of the sixth zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

20           Fig. 43 is an aberration diagram for Example 6-3 of the sixth zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

25           Fig. 44 is illustrative in section of one exemplary one-piece lens used in Example 6-1 of the sixth zoom optical system.

            Fig. 45 is illustrative in section of one exemplary

one-piece lens used in Example 6-2 of the sixth zoom optical system.

Fig. 46 is illustrative in section of one exemplary one-piece lens used in Example 6-3 of the sixth zoom optical system.

Fig. 47 is illustrative in lens section of Example 7-1 of the seventh zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 48 is illustrative in lens section of Example 7-2 of the seventh zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 49 is illustrative in lens section of Example 7-3 of the seventh zoom optical system, showing lens sections at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 50 is an aberration diagram for Example 7-1 of the seventh zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 51 is an aberration diagram for Example 7-2 of the seventh zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at

a telephoto end (c) upon focusing on an infinite object point.

Fig. 52 is an aberration diagram for Example 7-3 of the seventh zoom optical system, showing aberrations at a wide-angle end (a), in an intermediate setting (b) and at a telephoto end (c) upon focusing on an infinite object point.

Fig. 53 is illustrative in section of one exemplary one-piece lens used in Example 7-1 of the seventh zoom optical system.

Fig. 54 is illustrative in section of one exemplary one-piece lens used in Example 7-2 of the seventh zoom optical system.

Fig. 55 is illustrative in section of another exemplary one-piece lens used in Example 7-2 of the seventh zoom optical system.

Fig. 56 is illustrative in section of one exemplary one-piece lens used in Example 7-3 of the seventh zoom optical system.

Fig. 57 is a front perspective view of the appearance of a digital camera with a built-in inventive zoom optical system.

Fig. 58 is a rear perspective view of the digital camera of Fig. 57.

Fig. 59 is a sectional view of the digital camera of Fig. 57.

Fig. 60 is a front perspective view of a personal computer with a cover held open, wherein the zoom optical



system of the invention is incorporated in the form of an objective optical system.

Fig. 61 is a sectional view of a taking optical system in the personal computer.

5        Fig. 62 is a side view of the taking optical system in the state of Fig. 60.

      Figs. 63(a) and (b) are a front view and a side view of a cellular phone wherein the zoom optical systems of the invention is incorporated in the form of an objective  
10       optical system, and Fig. 63(c) is a sectional view of a taking optical system in it.

#### BEST MODES OF CARRYING OUT THE INVENTION

      The present invention provides a zoom optical system  
15       comprising a lens group having negative refracting power and a lens group having positive refracting power, wherein at least one lens is formed by molding of a first lens blank that provides a surface including at least an optical function surface after molding, and a second lens  
20       blank that provides a surface other than said surface including at least an optical function surface after molding, and the first lens blank and the second lens blank are integrated into a one-piece lens.

      A zoom optical system may generally be broken down  
25       into the following seven types:

      (1) the first group is a negative lens group, and the second group is a positive lens group;

      (2) the first group is a positive lens group, and

the second group is a negative lens group;

(3) the first group is a negative lens group, the second group is a positive lens group, and the third group is a positive lens group;

5       (4) the first group is a negative lens group, the second group is a positive lens group, the third group is a positive lens group, and the fourth group is a negative lens;

10       (5) the first group is a negative lens group, the second group is a positive lens group, the third group is a negative lens group, and the fourth group is a positive lens group;

15       (6) the first group is a negative lens group, the second group is a positive lens group, the third group is a positive lens group, and the fourth group is a positive lens group; and

20       (7) the first group is a positive lens group, the second group is a negative lens group, the third group is a positive lens group, and the fourth group is a positive lens group.

Each type will be described at great length later.

In such zoom optical systems, at least one one-piece lens should preferably satisfy the following condition (1) with respect to the thickness of its thinnest portion.

25                    $0.1 \text{ mm} < t < 0.5 \text{ mm} \quad \dots (1)$

Here  $t$  is the thickness of the thinnest portion of the one-piece lens.

The advantage of, and the requirement for, the above

arrangement is now explained. The reduction in the thickness of the thinnest portion of the one-piece lens enables it to be formed so small that the total length of the lens system can be made short. In other words, the  
5 satisfaction of condition (1) ensures that size reductions are achievable while optical performance is kept intact. As the lower limit of 0.1 mm to condition (1) is not reached, the lens becomes too thin to stand up deformation due to external pressure, temperature, etc., having  
10 difficulty in keeping the optical performance. Exceeding the upper limit of 0.5 mm causes the thinnest portion to become large, rendering the lens large.

More preferably, the following condition (1-2) should be satisfied, so that the optical system can be  
15 more slimmed down while the optical performance is maintained.

$$0.15 \text{ mm} < t < 0.4 \text{ mm} \quad \dots (1-2)$$

Even more preferably, the following condition (1-3) should be satisfied, so that the optical system can be  
20 much more slimmed down while the optical performance is maintained.

$$0.2 \text{ mm} < t < 0.35 \text{ mm} \quad \dots (1-3)$$

For the one-piece lens that satisfies the above conditions, it is also preferable to have positive  
25 refracting power.

The advantage of, and the requirement for, this arrangement is now explained. With the positive lens formed as a one-piece lens, its edge thickness difference

can be diminished, resulting in a decrease in the total length of the lens system.

When the one-piece lens is molded, it is preferable to simultaneously form a plurality of optical function  
5 surfaces on a single molding machine.

The advantage of, and the requirement for, this arrangement is now explained. Simultaneous formation of a plurality of parallel optical function surfaces on a single molding machine allows for a reduction in the  
10 processing time for each surface, and ensues as well that the service life of a press per the number of surfaces is extended. Therefore, some significant cost reductions are achievable.

Preferably, the first lens blank should be a glass.

15 The advantage of, and the requirement for, this arrangement is now explained. Use of a high-refractive-index glass as the first lens blank allows for satisfactory correction of various aberrations such as spherical aberrations and field curvature with a fewer  
20 lenses. The glass is less susceptible of influences of temperature changes. It is thus possible to achieve an optical system that has limited back focus fluctuations with temperature changes. It is understood that plastic or organic-inorganic composite lens blanks could be used  
25 as the first lens blank.

Preferably, the second lens blank should have shading capability.

The advantage of, and the requirement for, this

arrangement is now explained. With the shading capability of the second lens blank, light rays coming from surfaces other than the optical function surface arriving at the image plane can be so minimized that ghost light and flare  
5 light can be prevented.

Preferably, the second lens blank should be a metal, cermet or ceramics.

The advantage of, and the requirement for, this arrangement is now explained. If the second lens blank is  
10 a metal, cermet (a ceramic-metal composite lens blank) or ceramics, shaping is easily achievable.

Preferably, an organic-inorganic composite lens blank should be used as an optical lens blank for at least one optical element that forms a part of the optical  
15 system.

The advantage of, and the requirement for, this arrangement is now explained. As the organic-inorganic composite material is used as the optical material of an optical element, it allows various optical properties  
20 (refractive index, chromatic dispersion) to show up (or be obtained) depending on the types and content ratios of the organic and inorganic components. Thus, if the organic and inorganic components are blended at any desired ratio, it is then possible to achieve optical materials having  
25 the desired, or higher, optical properties. This in turn enables an optical element having ever high performance to be so obtained that various aberrations can be corrected with a fewer lenses, resulting in cost savings and size

reductions of an optical system.

Preferably, the organic-inorganic composite material should contain zirconia in a nano-particle form.

Preferably, the organic-inorganic composite material  
5 should contain zirconia and alumina in a nano-particle form.

Preferably, the organic-inorganic composite material should contain a niobium oxide in a nano-particle form.

Preferably, the organic-inorganic composite material  
10 should contain a zirconium alkoxide hydrolyzate and alumina in a nano-particle form.

The advantage of, and the requirement for, this arrangement is now explained. These inorganic materials in a nano-particle form are examples of the inorganic  
15 component. If such nano-particles are dispersed through the organic component, typically a plastic component at a given ratio, various optical properties (refractive index, chromatic dispersion) can then be developed.

How to fabricate the one-piece lens is explained  
20 with reference to Fig. 1. Referring to Fig. 1(a), reference numerals 14 and 15 represent a bottom force and a top force of a one-piece lens molding press, respectively. At a given area of the bottom force 14, there is provided a one-piece lens bottom surface dish  
25 (hereinafter called simply the bottom surface dish), which corresponds to an optical function surface portion of the post-molding one-piece lens. At a given area of the top force 15, too, there is provided a one-piece lens top

cavity (hereinafter called simply the top surface cavity), which corresponds to an optical function surface portion of the post-molding one-piece lens.

A one-piece lens 10 is molded of a first lens blank 11 and a second lens blank 12. The first lens blank 11 is to be provided with a surface including at least an optical function surface after the formation of the one-piece lens by molding, and the second lens blank 12 is to be provided with a surface other than the surface including at least an optical function surface after the formation of the one-piece lens by molding. This surface other than the surface including an optical function surface is formed at and around the surface formed by the first lens blank 11. For instance, this surface is to provide a surface to contact a lens barrel to support the one-piece lens or a centering surface.

The second lens blank 12 is provided with a cavity 13. Therefore, when the one-piece lens 10 is fabricated, the first lens blank 11 is placed together with the second lens blank 12 on the bottom force 14 of the one-piece lens molding press, as shown in Fig. 1(a), while the first lens blank 11 is fitted into the cavity 13. In this state, the first lens blank 11 is heated to a temperature at which it is deformable, and which could be a suitable temperature higher than the transition point of the first lens blank 11. Then, when the suitable temperature is reached, the top force 15 of the one-piece lens molding press goes down from above until it contacts the surface of the second

lens blank 12. This permits the first lens blank 11 to be pressed by the bottom and top forces. As a result, the first lens blank 11 is molded into a form commensurate with the bottom and top forces, providing the one-piece  
5 lens 10, as shown generally in Fig. 1(b).

After removal of the top force 15 of Fig. 1(b), the one-piece lens 10 is easily released from within the bottom force 14. In the one-piece lens 10, the first lens blank 11 is integrally fused to the cavity in the second  
10 lens blank 12, as shown in the perspective view of Fig. 2. In Fig. 1, a set of the first and second lens blanks 11 and 12 are placed in a pair of forces 14 and 15 by way of illustration alone. Another embodiment of this arrangement is now explained.

15 In another embodiment of Fig. 3, a pair of bottom force 14 and top force 15 of a molding press are provided with a plurality of dishes in a parallel fashion. A plurality of the first and second lens blanks 11 and 12 are located in correspondence to the respective dishes.  
20 Thus, a plurality of one-piece lenses are simultaneously molded. In Fig. 3(a), reference numerals 14 and 15 are the bottom and top forces of the one-piece lens molding press. At a given area of the bottom force 14, there are provided a plurality of one-piece lens bottom surface  
25 dishes (hereinafter called simply the bottom surface dishes). These bottom surface dishes are each to provide an optical function surface portion of the post-molding one-piece lens. At a given area of the top force 15, too,



there are provided a plurality of one-piece lens top surface dishes (hereinafter called simply the top surface dishes). These top surface dishes, too, are each to provide an optical function surface portion of the post-  
5 molding one-piece lens.

As shown in Fig. 3(a), the one-piece lens of this embodiment, too, is molded of the first lens blank 11 and the second lens blank 12. The first lens blank 11 is to provide a surface including at least an optical function  
10 surface after the formation of an individual one-piece lens by molding, and the second lens blank 12 is to provide a surface other than the surface including at least an optical function surface after the formation of an individual one-piece lens by molding. This surface  
15 other than the surface including an optical function surface is formed at and around the surface formed by the first lens blank 11. For instance, this surface is to provide a surface to contact a lens barrel to support the one-piece lens or a centering surface.

20 The second lens blank 12 is provided with a plurality of cavities 13. In this embodiment, therefore, one-piece lenses are formed in an array fashion. Then, one-piece lenses 10' formed in an array fashion (hereinafter called the array lenses 10') are individually  
25 cut off to obtain individual one-piece lenses 10' as shown in Fig. 2. For the fabrication of the array lenses 10', a plurality of the first lens blanks 11 are placed together with the second lens blank 12 on the bottom force 14 of

the one-piece lens molding press, while the first lens blanks 11 are each fitted into the cavity 13. In this state, the first lens blanks 11 are heated to a temperature at which they are deformable, and which could  
5 be a suitable temperature higher than their transition point. Then, when the suitable temperature is reached, the top force 15 of the one-piece lens press goes down from above until it contacts the surface of the second lens blank 12. This permits the first lens blanks 11 to  
10 be each pressed by the bottom and top forces. As a result, the first lens blanks 11 are formed in a form commensurate with the bottom and top dishes, giving the array lenses 10', as shown generally in Fig. 3(b).

In this embodiment, rims 16 are provided on the top  
15 force 15, as shown in Fig. 3. The rims 16 are transferred onto the second lens blank in a slot form simultaneously with molding. After removal of the top force 15 of Fig. 3(b), the array lenses 10' are easily released from within the bottom force 14. In these array lenses 10', the first  
20 lens blanks 11 are each integrally fused to the cavity 13 in the second lens blank 12. Thereafter, the second lens blank 12 is cut off to obtain a plurality of one-piece lenses 10. In Figs. 3 and 4, a 3x3 lens array is shown; however, how many lenses are to be obtained is not  
25 critical.

Yet another embodiment is shown in Figs. 5 and 6. This embodiment is different from the embodiment of Figs.

3 and 4 only in that there are no rims 16 on the top force 15. Thus, the second lens blank 12 has no slots 17.

Each type of the zoom optical system is now explained.

- 5           (1)   First of all, reference is made to the type wherein the first group is a negative lens group and the second group is a positive lens group.

          The first zoom optical system of the invention comprises, in order from its object side, a first group  
10   having negative refracting power and a second group having positive refracting power, wherein at least one lens is formed by molding of a first lens blank that provides a surface including at least an optical function surface after molding and a second lens blank that provides a  
15   surface other than the surface including at least an optical function surface after molding. In other words, at least one lens comprises a one-piece lens wherein the first lens blank and the second lens blank are integrated together.

20           The advantage of, and the requirement for, the above arrangement is now explained. Such a zoom optical system of negative-positive group construction can be set up with a reduced number of lenses, and so is best suited for size reductions and cost savings. With the one-piece lens,  
25   further size reductions are achievable. This is because for the one-piece lens any peripheral thickness for rounding is not required, when compared with the prior art lens processing, as described just below.

For the prior art lens processing, rounding is essential. For this reason, the outer peripheral portion of a lens prior to rounding must have some thickness or edge thickness difference, resulting in an increased  
5 center thickness (the thickness of a center portion). However, the one-piece lens for use with the first zoom optical system has a limited edge thickness difference, so that the optical system can be diminished in total length. With the prior art lens processing, the stronger the power  
10 of a positive lens, the larger the thickness of its outer peripheral portion becomes at the necessary outer diameter. For the first zoom optical system, however, it is not necessary to ensure the thickness of the outer peripheral portion at the time of rounding. Therefore, the stronger  
15 the power of the positive lens, the more significant the effect on size reductions becomes.

Such a one-piece lens is also easy to handle, leading to savings of the cost for zoom lens system fabrication.

20 With the first zoom optical system, zooming from its wide-angle end to its telephoto end, for instance, is carried out as follows. The first group moves in a concave locus toward the object side, and the second lens group moves toward the object side.

25 Preferably for the first zoom optical system, the one-piece lens should be cemented to other lens.

The advantage of, and the requirement for, the above arrangement is now explained. If the one-piece lens is

cemented to other lens as mentioned above, the sensitivity to decentration (decentration errors) can then be more reduced as compared with the case where individual lenses are independently assembled. Therefore, setting up the  
5 optical system becomes easy, leading to low costs.

Preferably for the first zoom optical system, at least one optical function surface of the one-piece lens should be an aspheric surface. To put it another way, the one-piece lens should be an aspheric one-piece lens.

10 The advantage of, and the requirement for, the above arrangement is now explained. The use of such an aspheric surface ensures that various aberrations are held back, with the result that the number of lenses in the whole system can be diminished, and size reductions and cost  
15 savings are achievable as well.

Preferably for the first zoom optical system, the first group should comprise at least one positive lens.

The advantage of, and the requirement for, the above arrangement is now explained. The first group, because of  
20 having negative power, includes at least one negative lens. Therefore, if the positive lens is incorporated in the first group, it is then possible to hold back fluctuations with zooming of various aberrations inclusive of spherical aberrations, coma and chromatic aberration of  
25 magnification.

Preferably for the first zoom optical system, the first group should include a negative lens nearest to its object side.

The advantage of, and the requirement for, the above arrangement is now explained. With this arrangement, the effective diameter of the lenses in the first group and the total length of the lens system can be shortened.

5            Preferably for the first zoom optical system, the first group should comprise at least one one-piece lens.

The advantage of, and the requirement for, the above arrangement is now explained. Because the lenses in the first group have a large effective diameter, there is an  
10 increase in the volume necessary for it. Therefore, if the one-piece lens is used for any of the lenses in the first group, the volume of the optical material can then be diminished. As a result, cost reductions are achievable.

15            Also, because the volume of the lenses themselves becomes small, the optical system can be slimmed down. Further, because the one-piece lens is easy to handle, the cost for the fabrication of the optical system can be cut short.

20            Preferably for the first zoom optical system, at least one of the one-piece lenses in the first group should have positive refracting power.

The advantage of, and the requirement for, the above arrangement is now explained. For correction of chromatic  
25 aberration of magnification, etc., it is preferable to locate a positive lens in the first group. Here, if a one-piece lens is used as this positive lens, it is then possible to make the edge thickness difference of the

positive lens small and, hence, shorten the total length of the lens system.

Preferably for the positive lens in the first group, it is preferable to use a high-refractive-index, high-dispersion optical material for the purpose of correcting chromatic aberration of magnification, and spherical aberrations, etc. at the telephoto end. It is generally noted that the high-refractive-index, high-dispersion material costs much. To add up to this, for the positive lens in the first lens group, it is required to have a large volume, because of its large effective diameter. Here, if a one-piece lens is used as this positive lens, it is then possible to decrease the volume of the optical material necessary for the positive lens. Therefore, cost reductions are achievable. Further, the volume of the lens itself becomes small, and so the optical system can be slimmed down.

Preferably for the first zoom optical system, at least one positive lens in the first group should satisfy the following condition.

$$0.1 < HH1/\phi 1 < 10 \quad \dots (2A)$$

Here, HH1 is the principal point spacing (mm) of the positive lens in the first group, and  $\phi 1$  is the refracting power of the positive lens in the first group.

The advantage of, and the requirement for, the above arrangement is now explained. With a negative lens located in the first group (and nearest to its object

side), there is chromatic aberration of magnification. To correct the chromatic aberration of magnification, etc. with a fewer lenses, i.e., at low costs, it is preferable to have a positive lens of increased power in the first  
5 group.

With the prior art lens processing, however, a lens is formed somewhat larger than the necessary outer diameter, and rounding is carried out in such a way as to incorporate it in a lens barrel. For this reason, when a  
10 positive lens is formed by molding, the thickness of its outer peripheral portion at the necessary outer diameter becomes larger than that of the lens at the time of rounding. Further, as the power of the positive lens increases, the thickness of the outer peripheral portion  
15 at the necessary outer diameter becomes far larger because of the need of ensuring the outer peripheral thickness of the lens at the time of rounding. As a result, it is difficult to make a sensible compromise between the reduction in the whole lens length and the size reduction  
20 of each lens or between cost savings and size reductions.

However, if a one-piece lens is used as the positive lens in the first group, it is unnecessary to form the positive lens larger than the necessary outer diameter, and the satisfaction of condition (2A) enables large power  
25 to be achieved with a thin lens. It is thus possible to achieve cost savings and size reductions at the same time.

As the lower limit of 0.1 to condition (2A) is not reached, the power becomes too large relative to the



principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As the upper limit of 10 is exceeded, the power becomes small  
5 relative to the principal point spacing. Thus, chromatic aberration of magnification or the like produced at the negative lens in the first group remains undercorrected. Alternatively, more lenses must be used for correction of chromatic aberration of magnification or the like.

10 More preferably,

$$0.5 < HH1/\phi 1 < 6 \quad \dots (2A-2)$$

In this case, the optical system can be more slimmed down at the same low cost.

Even more preferably,

15  $1 < HH1/\phi 1 < 3 \quad \dots (2A-3)$

In this case, the optical system can be much more slimmed down at the same low cost.

Preferably for the first zoom optical system, at least one one-piece lens in the first group should have at  
20 least one aspheric surface.

The advantage of, and the requirement for, the above arrangement is now explained. At the wide-angle end of the first zoom optical system, light rays gain height at the first group. For this reason, it is preferable to  
25 include at least one aspheric surface in the first group. This allows for good correction of off-axis aberrations such as astigmatism, distortion and coma with a fewer

lenses. Therefore, the optical system can be reduced in terms of both size and cost.

At the telephoto end, the diameter of a light beam through the first group grows large. Therefore, if at least one aspheric surface is included in the first group, spherical aberrations, coma, etc. can then be well corrected with a fewer lenses. In this case, too, the optical system can be reduced in terms of both size and cost.

10        Preferably for the first zoom optical system, the second group should comprise at least one negative lens.

The advantage of, and the requirement for, the above arrangement is now explained. The second group, because of having positive power, comprises at least one positive lens. Therefore, if it includes a negative lens, fluctuations with zooming of various aberrations such as coma, astigmatism and longitudinal chromatic aberration can then be held back.

20        Preferably for the first zoom optical system, the second group should have a positive lens located nearest to its object side.

The advantage of, and the requirement for, the above arrangement is now explained. At the second group, it is required to converge light diverged at the first group of negative power. Thus, the lens located nearest to the object side should preferably be a positive lens.

Preferably for the first zoom optical system, the second lens group should have a negative lens located

nearest to its image side.

The advantage of, and the requirement for, the above arrangement is now explained. The location of the negative lens nearest to the image side of the second group provides the two following advantages: (1) the principal point position displaces toward the first group side, so that the principal point spacing between the first group and the second group can be shortened, resulting in a decrease in the total length of the lens system; and (2) the second group is so increased in terms of magnification that the amount of movement of the second group with zooming can be decreased, resulting in a decrease in the total length.

Preferably for the first zoom optical system, the second group should comprise at least one one-piece lens and at least one of one-piece lenses should have positive refracting power.

The advantage of, and the requirement for, the above arrangement is now explained. The use of the one-piece lens as the positive lens allows for a decrease in the edge thickness difference of the positive lens, with the result that the whole length of the lens system can be shortened.

The positive lens in the second group should also preferably be formed of a high-refractive-index, low-dispersion optical material for the purpose of holding back longitudinal chromatic aberration, spherical aberration, astigmatism, etc. Commonly, however, the

high-refractive-index, low-dispersion optical material costs much. Therefore, it is preferable to use a one-piece lens for that positive lens, because the volume of the optical material necessary for the positive lens can  
5 be reduced and, hence, cost can be cut short.

Further, the volume of the lens itself becomes so small that the optical system can be slimmed down. Furthermore, since that one-piece lens is easy to handle, it is possible to cut short the cost for the fabrication  
10 of the zoom optical system.

Preferably for the first zoom optical system, at least one positive lens in the second group should satisfy the following condition.

$$0.1 < HH2/\phi 2 < 10 \quad \dots (3A)$$

15 Here, HH2 is the principal point spacing (mm) of the positive lens in the second group, and  $\phi 2$  is the refracting power of the positive lens in the second group.

The advantage of, and the requirement for, the above arrangement is now explained. By increasing the power of  
20 the positive lens located in the second group, the distance of movement of the second group can be made short. This leads to a reduction in the whole length of the lens system. However, the prior art lens processing has difficulty in reconciling the reduction in the whole  
25 length of the lens system with slimming down each lens, as already detailed with reference to condition (2A).

However, if that positive lens is molded as a one-

piece lens, it is then unnecessary to form it larger than the necessary outer diameter. The satisfaction of condition (3A) enables large power to be achieved with a thin lens. In this way, further size reductions are achievable.

5           As the lower limit of 0.1 to condition (3A) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As  
10 the upper limit of 10 is exceeded, the power becomes small relative to the principal point spacing, failing to decrease the amount of movement of the second group, and resulting in an increase in the whole length of the lens system.

15           It is more preferable to satisfy the following condition (3A-2), because the reduction in the whole length of the lens system can be reconciled with slimming down each lens.

$$0.5 < HH^2 / \phi^2 < 2 \quad \dots (3A-2)$$

20           It is even more preferable to satisfy the following condition (3A-2), because the tradeoff between the reduction in the whole length of the lens system and slimming down each lens is more easily achievable.

$$1 < HH^2 / \phi^2 < 1.5 \quad \dots (3A-3)$$

25           Preferably for the first zoom optical system, at least one one-piece lens in the second group should be cemented to other lens.

The advantage of, and the requirement for, the above arrangement is now explained. The incorporation of a cemented lens in the second group allows for a decrease in the sensitivity to decentration, which in turn makes the assembling of the optical system easy, leading to cost savings.

Preferably for the first zoom optical system, at least one one-piece lens in the second group should have at least one aspheric surface.

10       The advantage of, and the requirement for, the above arrangement is now explained. The first group has negative refracting power. In this case, a light beam is enlarged through the first group into a light beam of larger diameter, which is then incident on the second  
15       group. Thus, the light beam through the second group has a larger diameter, and if at least one aspheric surface is introduced in the second group, good aberration correction can be made. For lens diameter reductions, the power of each group must be increased. As the positive power of  
20       the second group increases, however, there are large transverse magnification and aberration changes of the second group with zooming. If the aspheric surface is introduced in the second group, it is possible to make correction for aberrations produced at the second group  
25       and hold back aberration fluctuations with zooming.

(2)     Reference is then made to the type wherein the first group is a positive lens group and the second group is a negative lens group.

The second zoom optical system of the invention comprises, in order from its object side, a first group having positive refracting power and a second group having negative refracting power, wherein at least one lens is  
5 formed by molding of a first lens blank that provides a surface including at least an optical function surface after molding and a second lens blank that provides a surface other than the surface including at least an optical function surface after molding. In other words,  
10 at least one lens comprises a one-piece lens wherein the first lens blank and the second lens blank are integrated together.

The advantage of, and the requirement for, the above arrangement is now explained. As in the zoom optical  
15 system of negative-positive group construction, the zoom optical system of such negative-positive group construction can be set up with a reduced number of lenses, and so is best suited for size reductions and cost savings. With the one-piece lens, further size reductions are  
20 achievable. This is because for the one-piece lens any peripheral thickness for rounding is not required, when compared with the prior art lens processing, as previously described in conjunction with the first zoom optical system.

25 Such a one-piece lens is also easy to handle, leading to savings of the cost for zoom lens system fabrication.

Here, with the second zoom optical system, zooming

from the wide-angle end to the telephoto end, for instance,  
is carried out as described just below. The first group  
and the second group move to the object side of the  
optical system while the space between the first group and  
5 the second group becomes narrow.

Preferably for the second zoom optical system, the  
one-piece lens should be cemented to other lens, and at  
least one optical function surface should be an aspheric  
surface. In other words, the one-piece lens should  
10 preferably be an aspheric one-piece lens.

The advantage of, and the requirement for, the above  
arrangement is the same as in the first zoom optical  
system.

Preferably for the second zoom optical system, the  
15 first group should comprise at least one negative lens.

The advantage of, and the requirement for, the above  
arrangement is now explained. The first group, because of  
having positive power, includes at least one positive lens.  
Therefore, if the negative lens is incorporated in the  
20 first group, it is then possible to hold back fluctuations  
with zooming of various aberrations inclusive of spherical  
aberration, coma and chromatic aberration of magnification.

Preferably for the second zoom optical system, the  
first group should include a positive lens nearest to its  
25 image side.

The advantage of, and the requirement for, the above  
arrangement is now explained. The location of the  
positive lens nearest to the image side of the first group



allows for a decrease in the spacing between the rear principal point of the first group and the front principal point of the second group, resulting in the achievement of size reductions.

5            Preferably for the second zoom optical system, the first group should comprise at least one one-piece lens, wherein the one-piece lens is a positive lens.

            The advantage of, and the requirement for, the above arrangement is the same as in the first zoom optical  
10    system. The use of the one-piece lens as the positive lens enables the edge thickness difference of the positive lens to become small. Therefore, the whole length of the lens system can be shortened.

            Preferably for the second zoom optical system, the  
15    positive lens in the first group should satisfy the following condition.

$$0.1 < HH1/\phi 1 < 15 \quad \dots (2B)$$

            Here, HH1 is the principal point spacing (mm) of the positive lens in the first group, and  $\phi 1$  is the refracting  
20    power of the positive lens in the first group.

            The advantage of, and the requirement for, the above arrangement is now explained. In order from the optical system to be of a telephoto type having a shortened total length, it is preferable that the positive lens in the  
25    first group have large power. However, the prior art lens processing has difficulty in offering a sensible tradeoff between low cost and slimming-down, as already detailed in

conjunction with the first zoom optical system.

However, if a one-piece lens is used as the positive lens in the first group, it is unnecessary to form the positive lens larger than the necessary outer diameter, and the satisfaction of condition (2B) enables large power to be achieved with a thin lens. It is thus possible to achieve cost savings and size reductions at the same time.

As the lower limit of 0.1 to condition (2B) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As the upper limit of 15 is exceeded, the effect of the telephoto type becomes slender, because the power becomes small relative to the principal point spacing. Therefore, the whole length of the lens system becomes long. Alternatively, a lot more lenses must be used for setting up the telephoto type.

It is more preferable to satisfy the following condition (2B-2). In this case, the reduction in the whole length of the lens system and slimming down each lens are achievable at the same time.

$$0.5 < HH1/\phi 1 < 6 \quad \dots (2B-2)$$

It is even more preferable to satisfy the following condition (2B-3). In this case, it is easier to achieve the reduction in the whole length of the lens system and slimming down each lens at the same time.

$$1 < HH1/\phi 1 < 2 \quad \dots (2B-3)$$

Preferably for the second zoom optical system, at least one one-piece lens in the first group should be cemented to other lens.

5        The advantage of, and the requirement for, the above arrangement is now explained. By the incorporation of such a cemented lens in the first group, the sensitivity to decentration can be so diminished that the assembling of the optical system is facilitated, leading to cost  
10 savings.

Preferably for the second zoom optical system, at least one one-piece lens in the first group should have at least one aspheric surface.

The advantage of, and the requirement for, the above  
15 arrangement is now explained. In the zoom optical system of positive-negative group construction, there is a large light beam diameter at the first group. Therefore, if at least one aspheric surface is included in the first group, spherical aberration, coma or other aberrations can then  
20 be well corrected.

Preferably for the second zoom optical system, the second group should comprise at least one positive lens.

The advantage of, and the requirement for, the above  
arrangement is now explained. At the wide-angle end of  
25 the zoom optical system of positive-negative group construction, light rays gain height at the second group. Therefore, if at least one positive lens is included in

the second group, fluctuations with zooming of various aberrations such as astigmatism and chromatic aberration of magnification can then be held back.

At the telephoto end, a light beam through the  
5 second group has a large diameter. Therefore, if at least one positive lens is introduced in the second group, fluctuations with zooming of spherical aberration, coma, etc. can then be held back.

Preferably for the second zoom optical system, the  
10 second group should have a negative lens nearest to its image side.

The advantage of, and the requirement for, the above arrangement is now explained. The location of the negative lens nearest to the image side of the second  
15 group provides the two following advantages: (1) the principal point position displaces toward the first group side, so that the principal point spacing between the first group and the second group can be shortened, resulting in a decrease in the total length of the lens  
20 system; and (2) the second group is so increased in terms of magnification that the amount of movement of the second group with zooming can be decreased, resulting in a decrease in the total length.

Preferably for the second zoom optical system, the  
25 second group should comprise at least one one-piece lens.

The advantage of, and the requirement for, the above arrangement is now explained. The second group, because of having a large effective diameter, grows large in terms

of the necessary volume. Therefore, if the one-piece lens is used for the lens in the second group, the volume of the optical material can then be diminished, resulting in cost savings.

5           Also, because the volume of the one-piece lens itself becomes small, the optical system can be slimmed down. In addition, the one-piece lens is so easy to handle that the cost for the fabrication of the optical system can be cut short.

10           Preferably for the second zoom optical system, at least one of the one-piece lenses in the second group should be a positive lens.

          The advantage of, and the requirement for, the above arrangement is now explained. If the one-piece lens is  
15       used as the positive lens, the edge thickness difference of the positive lens can then be diminished, resulting in a reduction in the whole length of the lens system.

          The positive lens in the second group should also preferably be formed of a high-refractive-index, low-  
20       dispersion optical material for the purpose of holding back chromatic aberration of magnification, spherical aberration, etc. Commonly, however, the high-refractive-index, low-dispersion optical material costs much. In addition, to be more effective, the positive lens in the  
25       second group increases in the necessary volume. Therefore, it is preferable to use a one-piece lens for that positive lens, because the volume of the optical material necessary for the positive lens can be reduced and, hence, cost can

be cut short.

Further, the volume of the lens itself becomes so small that the optical system can be slimmed down.

Furthermore, since that one-piece lens is easy to handle,  
5 it is possible to cut short the cost for the fabrication of the zoom optical system.

Preferably for the second zoom optical system, at least one positive lens in the second group should satisfy the following condition.

10 
$$0.1 < HH2/\phi2 < 6 \quad \dots (3B)$$

Here, HH2 is the principal point spacing (mm) of the positive lens in the second group, and  $\phi2$  is the refracting power of the positive lens in the second group.

The advantage of, and the requirement for, the above  
15 arrangement is now explained. By increasing the power of the positive lens located in the second group, the lens system is permitted to be of the telephoto type, leading to a decrease in the whole length of the lens system. At the wide-angle end, astigmatism and chromatic aberration  
20 of magnification fluctuations with zooming are well correctable with a fewer lenses, and at the telephoto end, fluctuations with zooming of various aberrations such as spherical aberration and coma can be well corrected again with a fewer lenses. With the above arrangement that  
25 allows the lens system to be set up with a fewer lenses, size reductions and cost savings are thus achievable. Still, there is difficulty in reconciling the reduction in

the whole length of the lens system with slimming down each lens, as previously detailed with reference to the first zoom optical system.

However, if that positive lens is formed as a one-  
5 piece molded lens, it is then unnecessary to form it larger than the necessary outer diameter. The satisfaction of condition (3B) enables large power to be achieved with a thin lens. In this way, further size reductions are achievable.

10 As the lower limit of 0.1 to condition (3B) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As  
15 the upper limit of 6 is exceeded, the power becomes small relative to the principal point spacing and, hence, with one positive lens, it is difficult to hold back fluctuations of the above aberrations. In other words, a plurality of lenses must be used for obtaining good  
20 performance.

It is more preferable to satisfy the following condition (3B-2). In this case, good performance is obtainable with a reduced number of lenses.

$$0.5 < HH2/\phi^2 < 3 \quad \dots (3B-2)$$

25 It is even more preferable to satisfy the following condition (3B-3). In this case, it is easier to obtain good performance with a limited number of lenses.

$$1 < HH2/\phi 2 < 1.5 \quad \dots (3B-3)$$

Preferably for the second zoom optical system, at least one one-piece lens in the second group should have at least one aspheric surface.

5           The advantage of, and the requirement for, the above arrangement is now explained. At the second group, light rays gain height. Therefore, if at least one aspheric surface is introduced into the second group, it is then possible to make effective correction for off-axis  
10   aberrations like astigmatism and coma.

(3)   Reference is now made to the type wherein the first group is a negative lens group, the second group is a positive lens group and the third group is a positive lens group.

15           The third zoom optical system of the invention comprises, in order from its object side, a first group having negative refracting power, a second group having positive refracting power and a third group having positive refracting power, wherein at least one lens is  
20   formed by molding of a first lens blank that provides a surface including at least an optical function surface after molding and a second lens blank that provides a surface other than the surface including at least an optical function surface after molding. In other words,  
25   at least one lens comprises a one-piece lens wherein the first lens blank and the second lens blank are integrated together.



The advantage of, and the requirement for, the above arrangement is now explained. A zoom optical system comprising, in order from its object side, a lens group of negative refracting power, a lens group of positive  
5 refracting power and a lens group of positive refracting power, can be set up with a limited or reduced number of lenses, and so is best suited for size reductions and cost savings. With the one-piece lens, further size reductions are achievable. This is because for the one-piece lens  
10 any peripheral thickness for rounding is not required, when compared with the prior art lens processing, as previously described in conjunction with the first zoom optical system.

Such a one-piece lens is also so easy to handle that  
15 the cost for the fabrication of the zoom optical system can be cut short.

Here, with the third zoom optical system, zooming from its wide-angle end to its telephoto end, for instance, is at least carried out as described just below. The  
20 first group moves in a concave locus toward the object side, and the second group moves toward the object side. During zooming, the third group could move, too.

Preferably for the third zoom optical system, the one-piece lens should be cemented to other lens.

25 Preferably for the third zoom optical system, the one-piece lens should be an aspheric one-piece lens wherein at least one optical function surface is an aspheric surface.

Preferably for the third zoom optical system, the first group should comprise at least one positive lens.

Preferably for the third zoom optical system, the first group should have a negative lens located nearest to  
5 its object side.

Preferably for the third zoom optical system, the first group should comprise at least one one-piece lens.

Preferably for the third zoom optical system, at least one of the one-piece lenses should have positive  
10 refracting power.

The advantages of, and the requirements for, the above arrangements are the same as in the first zoom optical system.

Preferably for the third zoom optical system, at least one positive lens in the first group should satisfy  
15 the following condition.

$$0.1 < HH1/\phi_1 < 15 \quad \dots (2C)$$

Here, HH1 is the principal point spacing (mm) of the positive lens in the first group, and  $\phi_1$  is the refracting  
20 power of the positive lens in the first lens group.

The advantage of, and the requirement for, the above arrangement is the same as already detailed in conjunction with the first zoom optical system.

As the lower limit of 0.1 to condition (2C) is not  
25 reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has

difficulty in keeping the optical performance intact. As the upper limit of 15 is exceeded, the power becomes small relative to the principal point spacing. For this reason, chromatic aberration of magnification or other aberrations produced at the negative lens in the first group remain undercorrected. Otherwise, a lot more lenses must be used for correction of chromatic aberration of magnification or the like.

It is more preferable to satisfy the following condition (2C-2). In this case, the optical system can be more slimmed down at the same low cost.

$$0.5 < HH1/\phi 1 < 7 \quad \dots (2C-2)$$

It is even more preferable to satisfy the following condition (2C-3). In this case, the optical system can be much more slimmed down at the same low cost.

$$1 < HH1/\phi 1 < 4 \quad \dots (2C-3)$$

Preferably for the third zoom optical system, at least one one-piece lens in the first group should be cemented to other lens.

The advantage of, and the requirement for, the above arrangement is now explained. The incorporation of such a cemented lens in the first group enables the sensitivity to decentration to be so diminished that the assembling of the optical system can be facilitated, leading to cost savings.

Preferably for the third zoom optical system, at least one one-piece lens in the first group should have at

least one aspheric surface.

Preferably for the third zoom optical system, the second group should comprise at least one negative lens.

Preferably for the third zoom optical system, the  
5 second group should have a positive lens located nearest to its object side.

Preferably for the third zoom optical system, the second group should have a negative lens located nearest to its image side.

10 Preferably for the third zoom optical system, the second group should comprise at least one one-piece lens, wherein at least one of the one-piece lenses has positive refracting power.

The advantages of, and the requirements for, the  
15 above arrangements are the same as described in conjunction with the first zoom optical system.

Preferably for the third zoom optical system, at least one positive lens in the second group should satisfy the following condition.

20 
$$0.1 < HH2/\phi2 < 10 \quad \dots (3C)$$

Here, HH2 is the principal point spacing (mm) of the positive lens in the second group, and  $\phi2$  is the refracting power of the positive lens in the second group.

The advantage of, and the requirement for, the above  
25 arrangement is the same as described with reference to the first zoom optical system.

As the lower limit of 0.1 to condition (3C) is not

reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As  
5 the upper limit of 10 is exceeded, the power becomes small relative to the principal point spacing and, hence, the amount of movement of the second group can never be reduced, resulting in an increase in the whole length of the lens system.

10 It is more preferable to satisfy the following condition (3C-2). In this case, the reduction in the whole length of the lens system can be reconciled with slimming down each lens.

$$0.5 < HH2/\phi^2 < 2 \quad \dots (3C-2)$$

15 It is even more preferable to satisfy the following condition (3C-3). In this case, it is easier to offer a sensible compromise between the reduction in the whole length of the lens system and slimming down each lens.

$$1 < HH2/\phi^2 < 1.5 \quad \dots (3C-3)$$

20 Preferably for the third zoom optical system, at least one one-piece lens in the second group should have at least one aspheric surface.

The advantage of, and the requirement for, the above arrangement is now explained. A light beam incident on  
25 the first group having negative refracting power travels through it, where the diameter of the light beam is enlarged. Thus, the light beam incident on the second

group has a large diameter. Therefore, if at least one aspheric surface is introduced in the second group, fluctuations with zooming of various aberrations such as spherical aberration and coma can be well corrected with a more reduced number of lenses, so that the size and cost of the optical system can be reduced.

Preferably for the third zoom optical system, the third group should comprise at least one one-piece lens.

The advantage of, and the requirement for, the above arrangement is now explained. The lens in the third group, because of having a large effective area, increases in terms of the volume of the optical material necessary for it. Therefore, if the one-piece lens is used as the lens in the third group, the volume of that optical material can then be diminished with the result of cost savings. In addition, the one-piece lens is so easy to handle that the cost for the fabrication of the zoom optical system can be cut short.

Preferably for the third zoom optical system, at least one of the one-piece lenses in the third group should be a positive lens having positive refracting power.

The advantage of, and the requirement for, the above arrangement is now explained. If the one-piece lens is used as the positive lens, the edge thickness difference of that positive lens can then be so diminished that the whole length of the lens system can be shortened. The positive lens in the third group increases in terms of the volume of the optical material necessary for it by reason

of its large effective diameter. Therefore, if the one-piece lens is used as that positive lens, the volume of that optical material becomes small so that cost savings are achievable.

5            Preferably for the third zoom optical system, at least one positive lens in the third group should satisfy the following condition.

$$0.1 < HH3/\phi 3 < 20 \quad \dots (4C)$$

Here, HH3 is the principal point spacing (mm) of the  
10    positive lens in the third group and  $\phi 3$  is the refracting power of the positive lens in the third group.

          The advantage of, and the requirement for, the above arrangement is now explained. Increasing the power of the positive lens in the third group means that the general  
15    power of the third group becomes strong. Increasing the power of the positive lens in the third group provides the two following advantages: (1) at the wide-angle end, the exit pupil position is spaced away from the image plane, so that it is easy to ensure telecentric capability on the  
20    image side; and (2) the whole length of the lens system can be shortened, because the range of movement of the third group along the optical axis for focusing purposes can become narrow, and the space between it and the second group remains narrow as well. Still, it is difficult to  
25    offer a sensible tradeoff between the reduction in the whole length of the lens system and slimming down each lens, as set forth with reference to the prior art lens

processing regarding the first zoom optical system.

However, if that positive lens is formed as a one-piece molded lens, it is unnecessary to form it larger than the necessary outer diameter. The satisfaction of  
5 condition (4C) enables large power to be obtained with a thin lens, so that further size reductions are achievable.

As the lower limit of 0.1 to condition (4C) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an  
10 increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As the upper limit of 20 is exceeded, the exit pupil position at the wide-angle end comes close to the image plane, because the power becomes small relative to the principal  
15 point spacing. As a result, it is impossible to ensure telecentric capability on the image side.

It is more preferable to satisfy the following condition (4C-2). In this case, the reduction in the whole length of the lens system can be well reconciled  
20 with slimming down each lens.

$$0.5 < HH3/\phi 3 < 8 \quad \dots (4C-2)$$

It is even more preferable to satisfy the following condition (4C-3). In this case, it is easier to reconcile the reduction in the whole length of the lens system with  
25 slimming down each lens.

$$1 < HH3/\phi 3 < 5 \quad \dots (4C-3)$$

Preferably for the third zoom optical system, at



least one one-piece lens in the third group should have at least one aspheric surface.

The advantage of, and the requirement for, the above arrangement is now explained. Referring to the third zoom  
5 optical system, light rays at the third group gain height at the telephoto end. Therefore, if at least one aspheric surface is included in the third group, off-axis aberrations such as astigmatism, distortion and coma can then be well corrected with a more reduced number of  
10 lenses, so that the size and cost of the optical system can be reduced.

(4) Reference is made to the type wherein the first group is a negative lens group, the second group is a positive lens group, the third group is a positive lens  
15 group and the fourth group is a negative lens group.

The fourth zoom optical system of the invention comprises, in order from its object side, a first group having negative refracting power, a second group having positive refracting power, a third group having positive  
20 refracting power and a fourth group having negative refracting power, wherein at least one lens is formed by molding of a first lens blank that provides a surface including at least an optical function surface after molding and a second lens blank that provides a surface  
25 other than the surface including at least an optical function surface after molding. In other words, at least one lens comprises a one-piece lens wherein the first lens blank and the second lens blank are integrated together.

The advantage of, and the requirement for, the above arrangement is now explained. A zoom optical system comprising, in order from its object side, a lens group of negative refracting power, a lens group of positive refracting power, a lens group of positive refracting power and a lens group of negative refracting power, can be set up with a limited or reduced number of lenses, and so is best suited for size reductions and cost savings. With the one-piece lens, further size reductions are achievable. This is because for the one-piece lens any peripheral thickness for rounding is not required, when compared with the prior art lens processing, as previously described in conjunction with the first zoom optical system.

Such a one-piece lens is also so easy to handle that the fabrication cost of the zoom optical system can be cut short.

Here, with the fourth zoom optical system, zooming from its wide-angle end to its telephoto end, for instance, is at least carried out as described just below. Upon zooming, the space between the first group and the second group varies, and the space between the second group and the third group varies. It is noted that zooming could be carried out with a varying space between other lens groups and a varying space between the fourth group and an image plane, and the third group could be used as a moving lens group for focusing.

Preferably for the fourth zoom optical system, the

one-piece lens should be cemented to other lens, or the one-piece lens should be an aspheric one-piece lens wherein at least one optical function surface is an aspheric surface.

5            Preferably for the fourth zoom optical system, the first group should comprise at least one positive lens.

            Preferably for the fourth zoom optical system, the first group should have a negative lens located nearest to its object side.

10           Preferably for the fourth zoom optical system, the first group should comprise at least one one-piece lens.

            Preferably for the fourth zoom optical system, at least one of the one-piece lenses should have positive refracting power.

15           The advantages of, and the requirements for, the above arrangements are the same as in the first zoom optical system.

            Preferably for the fourth zoom optical system, at least one positive lens in the first group should satisfy  
20   the following condition.

$$0.1 < HH1/\phi 1 < 10 \quad \dots (2D)$$

Here, HH1 is the principal point spacing (mm) of the positive lens in the first group, and  $\phi 1$  is the refracting power of the positive lens in the first group.

25           The advantage of, and the requirement for, the above arrangement is the same as already set forth in conjunction with the first zoom optical system.

As the lower limit of 0.1 to condition (2D) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has  
5 difficulty in keeping the optical performance intact. As the upper limit of 10 is exceeded, the power becomes small relative to the principal point spacing. For this reason, chromatic aberration of magnification or other aberrations produced at the negative lens in the first group remain  
10 undercorrected. Otherwise, a lot more lenses must be used for correction of chromatic aberration of magnification or the like.

It is more preferable to satisfy the following condition (2D-2). In this case, the optical system can be  
15 more slimmed down at the same low cost.

$$0.5 < HH1/\phi_1 < 5 \quad \dots (2D-2)$$

It is even more preferable to satisfy the following condition (2D-3). In this case, the optical system can be much more slimmed down at the same low cost.

20  $1 < HH1/\phi_1 < 2.5 \quad \dots (2D-3)$

Preferably for the fourth zoom optical system, at least one one-piece lens should be cemented to other lens.

The advantage of, and the requirement for, the above arrangement is the same as in the third zoom optical  
25 system.

Preferably for the fourth zoom optical system, at least one one-piece lens in the first group should

comprise at least one aspheric surface.

Preferably for the fourth zoom optical system, the second group should comprise at least one negative lens.

Preferably for the fourth zoom optical system, the  
5 second group should have a positive lens located nearest to its object side.

Preferably for the fourth zoom optical system, the second group should have a negative lens located nearest to its image side.

10 Preferably for the fourth zoom optical system, the second group should comprise at least one one-piece lens, wherein at least one of the one-piece lenses has positive refracting power.

The advantages of, and the requirements for, the  
15 above arrangements are the same as described in conjunction with the first zoom optical system.

Preferably for the fourth zoom optical system, at least one positive lens in the second group should satisfy the following condition.

20 
$$0.1 < HH2/\phi2 < 10 \quad \dots (3D)$$

Here, HH2 is the principal point spacing (mm) of the positive lens in the second group, and  $\phi2$  is the refracting power of the positive lens in the second group.

The advantage of, and the requirement for, the above  
25 arrangement is the same as described with reference to the first zoom optical system.

As the lower limit of 0.1 to condition (3D) is not

reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As  
5 the upper limit of 10 is exceeded, the power becomes small relative to the principal point spacing and, hence, the amount of movement of the second group can never be reduced, resulting in an increase in the whole length of the lens system.

10 It is more preferable to satisfy the following condition (3D-2). In this case, the reduction in the whole length of the lens system can be reconciled with slimming down each lens.

$$0.5 < HH2/\phi2 < 5 \quad \dots (3D-2)$$

15 It is even more preferable to satisfy the following condition (3D-3). In this case, it is easier to offer a sensible compromise between the reduction in the whole length of the lens system and slimming down each lens.

$$1 < HH2/\phi2 < 3.5 \quad \dots (3D-3)$$

20 Preferably for the fourth zoom optical system, at least one one-piece lens in the second group should comprise at least one aspheric surface.

Preferably for the fourth zoom optical system, the third group should comprise at least one one-piece lens.

25 Preferably for the fourth zoom optical system, at least one of the one-piece lenses in the third group should be a positive lens having positive refracting power.

The advantage of, and the requirement for, the above arrangement is the same as in the third zoom optical system.

Preferably for the fourth zoom optical system, at least one positive lens in the third group should satisfy the following condition.

$$0.1 < HH3/\phi_3 < 20 \quad \dots (4D)$$

Here, HH3 is the principal point spacing (mm) of the positive lens in the third group and  $\phi_3$  is the refracting power of the positive lens in the third group.

The advantage of, and the requirement for, the above arrangement is the same as in the third zoom optical system.

As the lower limit of 0.1 to condition (4D) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As the upper limit of 20 is exceeded, the exit pupil position at the wide-angle end comes close to the image plane, because the power becomes small relative to the principal point spacing. As a result, it is impossible to ensure telecentric capability on the image side.

It is more preferable to satisfy the following condition (4D-2). In this case, the reduction in the whole length of the lens system can be well reconciled with slimming down each lens.

$$0.5 < HH3/\phi_3 < 9 \quad \dots (4D-2)$$

It is even more preferable to satisfy the following condition (4D-3). In this case, it is easier to reconcile the reduction in the whole length of the lens system with  
5 slimming down each lens.

$$1 < HH3/\phi_3 < 4 \quad \dots (4D-3)$$

Preferably for the fourth zoom optical system, at least one one-piece lens in the third group should comprise at least one aspheric surface.

10 The advantage of, and the requirement for, the above arrangement is now explained. Referring to the fourth zoom optical system, at the wide-angle end, the diameter of a light beam through the third group is large. Therefore, if at least one aspheric surface is introduced  
15 in the third group, fluctuations with zooming of various aberrations such as spherical aberration and coma can then be well corrected with a more reduced number of lenses, resulting in size reductions and cost savings of the optical system.

20 Preferably for the fourth zoom optical system, a one-piece lens should be used in the fourth group (or the fourth group should comprise at least one one-piece lens).

The advantage of, and the requirement for, the above arrangement is now explained. The volume of the optical  
25 material necessary for the lens in the fourth group becomes large because of its large effective diameter. Therefore, if a one-piece lens is used as that lens in the



fourth group, the volume of that optical material then becomes small, resulting in cost savings. The one-piece lens is also so easy to handle that the fabrication cost of the zoom optical system can be cut short.

5            Preferably for the fourth zoom optical system, at least one one-piece lens in the fourth group should comprise at least one aspheric surface.

            The advantage of, and the requirement for, the above arrangement is now explained. At the fourth group, light  
10    rays gain height. Therefore, if at least one aspheric surface is introduced in the fourth group, off-axis aberrations such as distortion and astigmatism can then be well corrected with a more reduced number of lenses, resulting in size reductions and cost savings of the  
15    optical system.

(5)    Reference is made to the type wherein the first group is a negative lens group, the second group is a positive lens group, the third group is a negative lens group and the fourth group is a positive lens group.

20            The fifth zoom optical system of the invention comprises, in order from its object side, a first group having negative refracting power, a second group having positive refracting power, a third group having negative refracting power and a fourth group having positive  
25    refracting power, wherein at least one lens is formed by molding of a first lens blank that provides a surface including at least an optical function surface after molding and a second lens blank that provides a surface

other than the surface including at least an optical function surface after molding. In other words, at least one lens comprises a one-piece lens wherein the first lens blank and the second lens blank are integrated together.

5           The advantage of, and the requirement for, the above arrangement is now explained. A zoom optical system comprising, in order from its object side, a lens group of negative refracting power, a lens group of positive refracting power, a lens group of negative refracting  
10 power and a lens group of positive refracting power, can be set up with a limited or reduced number of lenses, and so is best suited for size reductions and cost savings. With the one-piece lens, further size reductions are achievable. This is because for the one-piece lens any  
15 peripheral thickness for rounding is not required, when compared with the prior art lens processing, as previously described in conjunction with the first zoom optical system.

          Such a one-piece lens is also so easy to handle that  
20 the fabrication cost of the zoom optical system can be cut short.

          Here, with the fifth zoom optical system, zooming from its wide-angle end to its telephoto end, for instance, is carried out as described just below. Upon zooming, the  
25 second group and the third group move toward the object side in an independent fashion. It is understood that upon zooming, the first group or the first group, too, could move.

Preferably for the fifth zoom optical system, the one-piece lens should be cemented to other lens, and the one-piece lens should be an aspheric one-piece lens wherein at least one optical function surface is an  
5 aspheric surface.

Preferably for the fifth zoom optical system, the first group should comprise at least one positive lens.

Preferably for the fifth zoom optical system, the first group should have a negative lens located nearest to  
10 its object side.

Preferably for the fifth zoom optical system, the first group should comprise at least one one-piece lens.

Preferably for the fifth zoom optical system, at least one of the one-piece lenses should have positive  
15 refracting power.

The advantages of, and the requirements for, the above arrangements are the same as in the first zoom optical system.

Preferably for the fifth zoom optical system, at  
20 least one positive lens in the first group should satisfy the following condition.

$$0.1 < HH1/\phi 1 < 10 \quad \dots (2E)$$

Here, HH1 is the principal point spacing (mm) of the positive lens in the first group, and  $\phi 1$  is the refracting  
25 power of the positive lens in the first group.

The advantage of, and the requirement for, the above arrangement is the same as already set forth in

conjunction with the first zoom optical system.

As the lower limit of 0.1 to condition (2E) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As the upper limit of 10 is exceeded, the power becomes small relative to the principal point spacing. For this reason, chromatic aberration of magnification or other aberrations produced at the negative lens in the first group remain undercorrected. Otherwise, a lot more lenses must be used for correction of chromatic aberration of magnification or the like.

It is more preferable to satisfy the following condition (2E-2). In this case, the optical system can be more slimmed down at the same low cost.

$$0.5 < HH1/\phi 1 < 6 \quad \dots (2E-2)$$

It is even more preferable to satisfy the following condition (2E-3). In this case, the optical system can be much more slimmed down at the same low cost.

$$1 < HH1/\phi 1 < 4 \quad \dots (2E-3)$$

Preferably for the fifth zoom optical system, at least one one-piece lens in the first group should be cemented to other lens.

The advantage of, and the requirement for, the above arrangement is the same as in the third zoom optical system.

Preferably for the fifth zoom optical system, at least one one-piece lens in the first group should comprise at least one aspheric surface.

The advantage of, and the requirement for, the above  
5 arrangement is the same as in the first zoom optical system.

Preferably for the fifth zoom optical system, the second group should comprise at least one negative lens.

The advantage of, and the requirement for, the above  
10 arrangement is now explained. The second group, because of having positive power, comprises at least one positive lens. Therefore, if the negative lens is introduced in the second group, fluctuations of chromatic aberration of magnification or the like with zooming can then be held  
15 back.

Preferably for the fifth zoom optical system, the second group should have a positive lens located nearest to its object side.

Preferably for the fifth zoom optical system, the  
20 second group should have a negative lens located nearest to its image side.

Preferably for the fifth zoom optical system, the second group should comprise at least one one-piece lens, wherein at least one of the one-piece lenses has positive  
25 refracting power.

The advantages of, and the requirements for, the above arrangements are the same as described in conjunction with the first zoom optical system.

Preferably for the fifth zoom optical system, at least one positive lens in the second group should satisfy the following condition.

$$0.1 < HH2/\phi2 < 6 \quad \dots (3E)$$

5 Here, HH2 is the principal point spacing (mm) of the positive lens in the second group, and  $\phi2$  is the refracting power of the positive lens in the second group.

The advantage of, and the requirement for, the above arrangement is the same as described with reference to the  
10 first zoom optical system.

As the lower limit of 0.1 to condition (3E) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has  
15 difficulty in keeping the optical performance intact. As the upper limit of 6 is exceeded, the power becomes small relative to the principal point spacing and, hence, the amount of movement of the second group can never be reduced, resulting in an increase in the whole length of  
20 the lens system.

It is more preferable to satisfy the following condition (3E-2). In this case, the reduction in the whole length of the lens system can be reconciled with slimming down each lens.

25 
$$0.5 < HH2/\phi2 < 3 \quad \dots (3E-2)$$

It is even more preferable to satisfy the following condition (3E-3). In this case, it is easier to offer a

sensible compromise between the reduction in the whole length of the lens system and slimming down each lens.

$$1 < H^2 / \phi^2 < 2 \quad \dots (3E-3)$$

Preferably for the fifth zoom optical system, at least one one-piece lens in the second lens group should be cemented to other lens.

The advantage of, and the requirement for, the above arrangement is the same as described with reference to the first zoom optical system.

Preferably for the fifth zoom optical system, at least one one-piece lens in the second group should comprise at least one aspheric surface.

As a light beam is incident on the first group having negative refracting power, its diameter grows large. Therefore, if at least one aspheric surface is introduced in the second group, fluctuations of various aberrations can then be well corrected, resulting in the achievement of size reductions and cost savings. To decrease lens diameter, the power of each lens must be increased. As the positive power of the second group increases, however, there are significant changes in the transverse magnification and aberrations of the second group with zooming. Therefore, the second group should preferably include an aspheric surface for the purposes of making correction for aberrations produced at the second group and held back aberration fluctuations with zooming.

Preferably for the fifth zoom optical system, the

third group should comprise at least one one-piece lens.

The advantage of, and the requirement for, the above arrangement is now explained. As previously stated, the one-piece lens is so easy to handle that the fabrication  
5 cost of the zoom optical system can be cut short.

Preferably for the fifth zoom optical system, the fourth group should comprise at least one one-piece lens.

The advantage of, and the requirement for, the above arrangement is the same as set forth with reference to the  
10 fourth zoom optical system.

Preferably for the fifth zoom optical system, at least one of the one-piece lenses in the fourth group should be a positive lens having positive refracting power.

The advantage of, and the requirement for, the above  
15 arrangement is now explained. If the one-piece lens is used as the positive lens, the edge thickness difference of that positive lens can then be diminished, resulting in a decrease in the whole length of the lens system.

The volume of the optical material necessary for the  
20 lens in the fourth group grows large because of its large effective diameter. Therefore, if the one-piece lens is used as the lens in the fourth group, the volume of that optical material can then be decreased, resulting in cost savings. The one-piece lens is also so easy to handle  
25 that the fabrication cost of the zoom optical system can be cut short.

Preferably for the fifth zoom optical system, at least one positive lens in the fourth group should satisfy



the following condition.

$$0.1 < HH4/\phi 4 < 10 \quad \dots (5E)$$

Here, HH4 is the principal point spacing (mm) of the positive lens in the fourth group and  $\phi 4$  is the refracting power of the positive lens in the fourth group.

The advantage of, and the requirement for, the above arrangement is now explained.

The advantage of, and the requirement for, the above arrangement is now explained. Increasing the power of the positive lens in the fourth group means that the general power of the third group becomes strong, resulting in a reduction in the whole length of the lens system.

Increasing the power of the positive lens in the fourth group provides the following advantage: at the wide-angle end, the exit pupil position is spaced away from the image plane, so that it is easy to ensure telecentric capability on the image side. With the prior art lens processing, it is still difficult to offer a sensible tradeoff between the reduction in the whole length of the lens system and slimming down each lens, as set forth with reference to the prior art lens processing regarding the first zoom optical system.

However, if that positive lens is formed as a one-piece molded lens, it is unnecessary to form it larger than the necessary outer diameter. The satisfaction of condition (5E) enables large power to be obtained with a thin lens, so that further size reductions are achievable.

As the lower limit of 0.1 to condition (5E) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has  
5 difficulty in keeping the optical performance intact. Exceeding the upper limit of 10 is not preferable, because the power becomes small relative to the principal point spacing, and so the exit pupil position at the wide-angle end comes close to the image plane. As a result, it is  
10 impossible to ensure telecentric capability on the image side.

It is more preferable to satisfy the following condition (5E-2). In this case, the reduction in the whole length of the lens system and the achievement of  
15 telecentric capability on the image side can be well reconciled with slimming down each lens.

$$0.5 < HH4/\phi4 < 7 \quad \dots (5E-2)$$

It is even more preferable to satisfy the following condition (5E-3). In this case, it is easier to reconcile  
20 the reduction in the whole length of the lens system and the achievement of telecentric capability on the image side with slimming down each lens.

$$1 < HH4/\phi4 < 5 \quad \dots (5E-3)$$

(6) Reference is made to the type wherein the  
25 first group is a negative lens group, the second group is a positive lens group, the third group is a positive lens group and the fourth group is a positive lens group.

The sixth zoom optical system of the invention comprises, in order from its object side, a first group having negative refracting power, a second group having positive refracting power, a third group having positive  
5 refracting power and a fourth group having positive refracting power, wherein at least one lens is formed by molding of a first lens blank that provides a surface including at least an optical function surface after molding and a second lens blank that provides a surface  
10 other than the surface including at least an optical function surface after molding. In other words, at least one lens comprises a one-piece lens wherein the first lens blank and the second lens blank are integrated together.

The advantage of, and the requirement for, the above  
15 arrangement is now explained. A zoom optical system comprising, in order from its object side, a lens group of negative refracting power, a lens group of positive refracting power, a lens group of positive refracting power and a lens group of positive refracting power, can  
20 be set up with a limited or reduced number of lenses, and so is best suited for size reductions and cost savings. With the one-piece lens, further size reductions are achievable. This is because for the one-piece lens any peripheral thickness for rounding is not required, when  
25 compared with the prior art lens processing, as previously described in conjunction with the prior art lens processing regarding the first zoom optical system.

Such a one-piece lens is also so easy to handle that

the fabrication cost of the zoom optical system can be cut short.

Here, with the sixth zoom optical system, zooming from its wide-angle end to its telephoto end, for instance,  
5 is at least carried out as follows. Upon zooming, the first group moves in a concave locus toward the object side, and the second lens group moves toward the object side. It is understood that upon zooming, the third group and the fourth groups could move.

10 Preferably for the sixth zoom optical system, the one-piece lens should be cemented to other lens.

Preferably for the sixth zoom optical system, the one-piece lens should be an aspheric one-piece lens wherein at least one optical function surface is an  
15 aspheric surface.

Preferably for the sixth zoom optical system, the first group should comprise at least one positive lens.

Preferably for the sixth zoom optical system, the first group should have a negative lens located nearest to  
20 its object side.

Preferably for the sixth zoom optical system, the first group should comprise at least one one-piece lens.

Preferably for the sixth zoom optical system, at least one of the one-piece lenses should have positive  
25 refracting power.

The advantages of, and the requirements for, the above arrangements are the same as in the first zoom optical system.

Preferably for the sixth zoom optical system, at least one positive lens in the first group should satisfy the following condition.

$$0.1 < HH1/\phi_1 < 15 \quad \dots (2F)$$

5 Here, HH1 is the principal point spacing (mm) of the positive lens in the first group, and  $\phi_1$  is the refracting power of the positive lens in the first group.

The advantage of, and the requirement for, the above arrangement is the same as already set forth in  
10 conjunction with the first zoom optical system.

As the lower limit of 0.1 to condition (2F) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has  
15 difficulty in keeping the optical performance intact. As the upper limit of 15 is exceeded, the power becomes small relative to the principal point spacing. For this reason, chromatic aberration of magnification or other aberrations produced at the negative lens in the first group remain  
20 undercorrected. Otherwise, a lot more lenses must be used for correction of chromatic aberration of magnification or the like.

It is more preferable to satisfy the following condition (2F-2). In this case, the optical system can be  
25 more slimmed down at the same low cost.

$$0.5 < HH1/\phi_1 < 7 \quad \dots (2F-2)$$

It is even more preferable to satisfy the following

condition (2F-3). In this case, the optical system can be much more slimmed down at the same low cost.

$$1 < HH1/\phi 1 < 4 \quad \dots (2F-3)$$

Preferably for the sixth zoom optical system, at least one one-piece lens in the first group should be cemented to other lens.

The advantage of, and the requirement for, the above arrangement is the same as in the third zoom optical system.

10        Preferably for the sixth zoom optical system, at least one one-piece lens in the first group should have at least one aspheric surface.

The advantage of, and the requirement for, the above arrangement is now explained. Referring to the sixth zoom optical system, at the wide-angle end, the diameter of a light beam through the third group is large. Therefore, if at least one aspheric surface is introduced in the third group, fluctuations with zooming of various aberrations such as spherical aberration and coma can then be well corrected with a more reduced number of lenses, resulting in size reductions and cost savings of the optical system.

At the telephoto end, on the other hand, the diameter of a light beam through the first group grows large. Therefore, if at least one aspheric surface is introduced in the third group, fluctuations with zooming of various aberrations such as spherical aberration and

coma can then be well corrected with a more reduced number of lenses, again resulting in size reductions and cost savings of the optical system.

Preferably for the sixth zoom optical system, the  
5 second group should comprise at least one negative lens.

Preferably for the sixth zoom optical system, the second group should have a positive lens located nearest to its object side.

Preferably for the sixth zoom optical system, the  
10 second group should have a negative lens located nearest to its image side.

Preferably for the fifth zoom optical system, the second group should comprise at least one one-piece lens, wherein at least one of the one-piece lenses has positive  
15 refracting power.

The advantages of, and the requirements for, the above arrangements are the same as described in conjunction with the first zoom optical system.

Preferably for the sixth zoom optical system, at  
20 least one positive lens in the second group should satisfy the following condition.

$$0.1 < HH2/\phi 2 < 10 \quad \dots (3F)$$

Here, HH2 is the principal point spacing (mm) of the positive lens in the second group, and  $\phi 2$  is the  
25 refracting power of the positive lens in the second group.

The advantage of, and the requirement for, the above arrangement is the same as described with reference to the

first zoom optical system.

As the lower limit of 0.1 to condition (3F) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As the upper limit of 10 is exceeded, the power becomes small relative to the principal point spacing and, hence, the amount of movement of the second group can never be reduced, resulting in an increase in the whole length of the lens system.

It is more preferable to satisfy the following condition (3F-2). In this case, the reduction in the whole length of the lens system can be reconciled with slimming down each lens.

$$0.5 < HH2/\phi^2 < 2 \quad \dots (3F-2)$$

It is even more preferable to satisfy the following condition (3F-3). In this case, it is easier to offer a sensible compromise between the reduction in the whole length of the lens system and slimming down each lens.

$$1 < HH2/\phi^2 < 1.5 \quad \dots (3F-3)$$

Preferably for the sixth zoom optical system, at least one one-piece lens in the second group should have at least one aspheric surface.

Preferably for the sixth zoom optical system, the third group should comprise at least one one-piece lens.

Preferably for the sixth zoom optical system, at



least one of the one-piece lenses in the third group should be a positive lens having positive refracting power.

Preferably for the sixth zoom optical system, at least one positive lens in the third group should satisfy  
5 the following condition.

$$0.1 < HH3/\phi 3 < 20 \quad \dots (4F)$$

Here, HH3 is the principal point spacing (mm) of the positive lens in the third group and  $\phi 3$  is the refracting power of the positive lens in the third group.

10 The advantage of, and the requirement for, the above arrangement is the same as set forth with reference to the third zoom optical system.

As the lower limit of 0.1 to condition (4F) is not reached, the power becomes too large relative to the  
15 principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. Exceeding the upper limit of 20 is not preferable, because the power becomes small relative to the principal point  
20 spacing, and so the exit pupil position at the wide-angle end comes close to the image plane. As a result, it is impossible to ensure telecentric capability on the image side.

It is more preferable to satisfy the following  
25 condition (4F-2). In this case, the reduction in the whole length of the lens system can be reconciled with slimming down each lens.

$$0.5 < HH3/\phi_3 < 8 \quad \dots (4F-2)$$

It is even more preferable to satisfy the following condition (4F-3). In this case, it is easier to reconcile the reduction in the whole length of the lens system with  
5 slimming down each lens.

$$1 < HH3/\phi_3 < 5 \quad \dots (4F-3)$$

Preferably for the sixth zoom optical system, at least one one-piece lens in the third group should have at least one aspheric surface.

10 Preferably for the sixth zoom optical system, the fourth group should comprise at least one one-piece lens.

The advantages of, and the requirements for, the above arrangements are the same as set forth in conjunction with the fourth zoom optical system.

15 Preferable for the sixth zoom optical system, the at least one of the one-piece lenses should have positive refracting power.

The advantage of, and the requirement for, the above arrangement is the same as set forth in connection with  
20 the fifth zoom optical system.

Preferably for the sixth zoom optical system, at least one positive lens in the fourth group should satisfy the following condition.

$$0.1 < HH4/\phi_4 < 20 \quad \dots (5F)$$

25 Here, HH4 is the principal point spacing (mm) of the positive lens in the fourth group and  $\phi_3$  is the refracting power of the positive lens in the fourth group.

The advantage of, and the requirement for, the above arrangement is the same as set forth with reference to the fifth zoom optical system.

As the lower limit of 0.1 to condition (5F) is not  
5 reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As the upper limit of 20 is exceeded, the power becomes small  
10 relative to the principal point spacing, and so the exit pupil position at the wide-angle end comes close to the image plane. As a result, it is impossible to ensure telecentric capability on the image side.

It is more preferable to satisfy the following  
15 condition (5F-2). In this case, the reduction in the whole length of the lens system and the telecentric capability on the image side can be reconciled with slimming down each lens.

$$0.5 < HH4/\phi 4 < 8 \quad \dots (5F-2)$$

20 It is even more preferable to satisfy the following condition (5F-3). In this case, it is easier to reconcile the reduction in the whole length of the lens system and the telecentric capability on the image side with slimming down each lens.

25  $1 < HH4/\phi 4 < 5 \quad \dots (5F-3)$

Preferably for the sixth zoom optical system, at least one one-piece lens in the third group should have at

least one aspheric surface.

The advantage of, and the requirement for, the above arrangement is now explained. At the wide-angle end, the diameter of a light beam through the fourth group becomes  
5 large. Therefore, if at least one aspheric surface is included in the fourth group, fluctuations with zooming of various aberrations such as spherical aberration and coma can then be well corrected with a reduced number of lenses. This is preferable to size reductions and cost savings.

10 (7) Reference is made to the type wherein the first group is a positive lens group, the second group is a negative lens group, the third group is a positive lens group and the fourth group is a positive lens group.

The seventh zoom optical system of the invention  
15 comprises, in order from its object side, a first group having positive refracting power, a second group having negative refracting power, a third group having positive refracting power and a fourth group having positive refracting power, wherein at least one lens is formed by  
20 molding of a first lens blank that provides a surface including at least an optical function surface after molding and a second lens blank that provides a surface other than the surface including at least an optical function surface after molding. In other words, at least  
25 one lens comprises a one-piece lens wherein the first lens blank and the second lens blank are integrated together.

The advantage of, and the requirement for, the above arrangement is now explained. A zoom optical system

comprising, in order from its object side, a lens group of positive refracting power, a lens group of negative refracting power, a lens group of positive refracting power and a lens group of positive refracting power, can  
5 be set up with a limited or reduced number of lenses, providing an optical system of high performance and having a fixed total length, and so is best suited for size reductions and cost savings. With the one-piece lens, further size reductions are achievable. This is because  
10 for the one-piece lens any peripheral thickness for rounding is not required, when compared with the prior art lens processing, as previously described in conjunction with the prior art lens processing regarding the first zoom optical system.

15       Such a one-piece lens is also so easy to handle that the fabrication cost of the zoom optical system can be cut short.

Here, with the seventh zoom optical system, zooming from its wide-angle end to its telephoto end, for instance,  
20 is carried out as follows. Upon zooming, the second group moves toward the image side, and the third group and the fourth group moves toward the object side with their space becoming wide. It is understood that the first group, too, could move during zooming.

25       Preferably for the seventh zoom optical system, the one-piece lens should be cemented to other lens.  
Preferably for the seventh zoom optical system, the one-piece lens should be an aspheric one-piece lens wherein at

least one optical function surface is an aspheric surface.

The advantages of, and the requirements for, the above arrangements are the same as set forth in conjunction with the first zoom optical system.

5            Preferably for the seventh zoom optical system, the first group should comprise at least one positive lens.

            The advantage of, and the requirement for, the above arrangement is now explained. The lens in the first group, because of having a large effective diameter, grows large  
10 in terms of the necessary volume. With one-piece lens used in the first lens group, however, the volume of the optical system can be diminished. As a result, cost savings are achievable. The volume of the lens itself, too, becomes so small that the optical system can be  
15 slimmed down. The one-piece lens is also so easy to handle that the fabrication cost of the optical system can be cut short.

            Preferably for the seventh zoom optical system, at least one of the one-piece lenses in the first group  
20 should have positive refracting power.

            The advantage of, and the requirement for, the above arrangement is now explained. For the positive lens in the first group, it is preferable to use a high-refractive-index, high-dispersion optical material so as  
25 to make correction for chromatic aberration, spherical aberration, etc. Commonly, however, the high-refractive-index, high-dispersion optical material costs much. In addition, the positive lens in the first group, because of

having a large effective diameter, grows large in terms of the necessary volume. However, it is preferable to use a one-piece lens as that positive lens, because the volume of such an optical material can be diminished, resulting  
5 in cost savings.

Also, the volume of the lens itself becomes so small that the optical system can be slimmed down. The use of a one-piece lens as the positive lens ensures that the edge thickness difference of the positive lens becomes small.  
10 Accordingly, the total length of the optical system can be shortened.

Preferably for the seventh zoom optical system, at least one positive lens in the first group should satisfy the following condition.

$$15 \qquad 0.1 < HH1/\phi 1 < 20 \qquad \dots (2G)$$

Here, HH1 is the principal point spacing (mm) of the positive lens in the first group, and  $\phi 1$  is the refracting power of the positive lens in the first group.

The advantage of, and the requirement for, the above  
20 arrangement is now explained. As the positive lens in the first group is weak, it incurs an increase in the total length of the lens system simultaneously with an increase the diameter of the front lens. Thus, the positive lens in the first group should preferably have large power.  
25 With the conventional lens processing, however, it is difficult to offer a sensible tradeoff between cost savings and size reductions, as detailed in conjunction

with the first zoom optical system.

However, if this positive lens is formed by molding as a one-piece lens, it is then unnecessary to form it larger than the necessary outer diameter. The  
5 satisfaction of condition (2G) enables larger power to be achieved by a thin lens. Thus, cost savings and size reductions are simultaneously achievable.

As the lower limit of 0.1 to condition (2G) is not reached, the power becomes too large relative to the  
10 principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As the upper limit of 20 is exceeded, the power becomes small relative to the principal point spacing. This does not  
15 only result in an increase in the total length of the lens system, but also incurs an increase in the diameter of the front lens, rendering the size reductions of the optical system difficult.

It is more preferable to satisfy the following  
20 condition (2G-2). In this case, the optical system can be more slimmed down at the same low cost.

$$0.5 < HH1/\phi 1 < 10 \quad \dots (2G-2)$$

It is even more preferable to satisfy the following condition (2G-3). In this case, the optical system can be  
25 much more slimmed down at the same low cost.

$$1 < HH1/\phi 1 < 5 \quad \dots (2G-3)$$

Preferably for the seventh zoom optical system, the



second group should comprise at least one positive lens.

The advantage of, and the requirement for, the above arrangement is now explained. The second group, because of having negative power, comprises at least one negative lens. Therefore, if a positive lens is included in the second group, fluctuations with zooming of various aberrations such as spherical aberration and chromatic aberration of magnification can then be held back.

Preferable for the seventh optical system, the second group should have a positive lens located nearest to its object side.

The advantage of, and the requirement for, the above arrangement is now explained. It is possible to reduce the effective diameters of the lenses in the second group and the whole length of the lens system.

Preferably for the seventh zoom optical system, the second group should comprise at least one one-piece lens.

The advantage of, and the requirement for, the above arrangement is the same as set forth in connection with the second zoom optical system.

Preferably for the seventh zoom optical system, at least one of the one-piece lenses in the second group should have positive refracting power.

The second group, because of having negative power, comprises at least one negative lens. Therefore, if a positive lens is included in the second group, fluctuations with zooming of various aberrations such as spherical aberration and chromatic aberration of

magnification can then be held back.

For the positive lens in the second group, it is preferable to use a high-refractive-index, high-dispersion optical material so as to make correction for chromatic  
5 aberration, spherical aberration, etc. Commonly, however, the high-refractive-index, high-dispersion optical material costs much. In addition, the positive lens in the second group, because of having a large effective diameter, grows large in terms of the necessary volume.  
10 Therefore, it is preferable to use a one-piece lens as that positive lens, because the volume of such an optical material can be diminished, resulting in cost savings.

Also, the volume of the lens itself becomes so small that the optical system can be slimmed down. The one-  
15 piece lens is also easy to handle that the fabrication cost of the optical system can be cut short.

Preferably for the seventh zoom optical system, at least one positive lens in the second group should satisfy the following condition.

$$20 \qquad 0.1 < HH2/\phi2 < 15 \qquad \dots (3G)$$

Here, HH2 is the principal point spacing (mm) of the positive lens in the second group, and  $\phi1$  is the refracting power of the positive lens in the second group.

The advantage of, and the requirement for, the above  
25 arrangement is now explained. To reduce the effective diameters of the lenses and the whole length of the lens system, it is preferable for the negative lens in the

second group to have large power. To make good correction for fluctuations of spherical aberration, coma, etc. with zooming, therefore, it is preferable for the second group to comprise a positive lens of large power. With the  
5 prior art lens processing, however, there is difficulty in balancing cost savings against size reductions, as detailed in conjunction with the first zoom optical system.

However, if this positive lens is formed by molding as a one-piece lens, it is then unnecessary to form it  
10 larger than the necessary outer diameter. The satisfaction of condition (3G) enables larger power to be achieved by a thin lens. Thus, cost savings and size reductions are simultaneously achievable.

As the lower limit of 0.1 to condition (3G) is not  
15 reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As the upper limit of 15 is exceeded, the power becomes small  
20 relative to the principal point spacing. This has difficulty in holding back fluctuations with zooming of various aberrations such as spherical aberration and coma produced at the negative lens in the second group. As a result, a lot more lenses will be needed to obtain  
25 satisfactory performance.

It is more preferable to satisfy the following condition (3G-2). In this case, the reduction in the overall length of the lens system can be reconciled with

slimming down each lens.

$$0.5 < HH2/\phi2 < 7 \quad \dots (3G-2)$$

It is even more preferable to satisfy the following condition (3G-3). In this case, it is easier to reconcile  
5 the reduction in the overall length of the lens system with slimming down each lens.

$$1 < HH2/\phi2 < 4 \quad \dots (3G-3)$$

Preferably for the sixth zoom optical system, at least one one-piece lens in the second group should be  
10 cemented to other lens.

The advantage of, and the requirement for, the above arrangement is the same as in the third zoom optical system.

Preferably for the seventh zoom optical system, at  
15 least one one-piece lens in the second group should have at least one aspheric surface.

The advantage of, and the requirement for, the above arrangement is now explained. Referring to the seventh zoom optical system, at the wide-angle end, light rays  
20 through the second group gain height. Therefore, if at least one aspheric surface is introduced in the second group, off-axis aberrations such as astigmatism, distortion, coma, etc. can then be well corrected with a more reduced number of lenses, leading to size reductions  
25 and cost savings of the optical system.

At the telephoto end, on the other hand, the diameter of a light beam through the second group grows

large. Therefore, if at least one aspheric surface is introduced in the second group, spherical aberration, coma and so on can then be well corrected with a more reduced number of lenses, again resulting in size reductions and cost savings of the optical system. Again, the optical system can be slimmed down at low costs.

Preferably for the seventh zoom optical system, the third group should comprise at least one negative lens.

The advantage of, and the requirement for, the above arrangement is now explained. The third group, because of having positive power, comprises at least one positive lens. Therefore, if a negative lens is included in it, fluctuations with zooming of various aberrations such as coma, astigmatism and longitudinal chromatic aberration can then be held back.

Preferably for the seventh zoom optical system, the third group should have a positive lens located nearest to its object side.

The advantage of, and the requirement for, the above arrangement is now explained. By locating the positive lens nearest to the object side of the third group, the principal points are allowed to move toward the second group, so that the principal point spacing between the second group and the third group can be shortened, leading to a reduction in the whole length of the lens system.

Preferably for the seventh zoom optical system, the third group should comprise at least one one-piece lens, wherein at least one of the one-piece lenses has positive

refracting power.

The advantage of, and the requirement for, the above arrangement is now explained. By using a one-piece lens as the positive lens, the edge thickness difference of the positive lens can be made so small that the whole length of the lens system can be shortened.

Preferably for the positive lens in the third group, it is preferable to use a high-refractive-index, low-dispersion optical material so as to hold back longitudinal chromatic aberration, spherical aberration, astigmatism, etc. Commonly, however, the high-refractive-index, low-dispersion optical material costs much. Therefore, if the positive lens is provided as a one-piece lens, then the volume of the optical material can be made small, resulting in cost savings.

The volume of the lens itself becomes so small that the optical system can be slimmed down. The one-piece lens is also easy to handle that the fabrication cost of the optical system can be cut short.

Preferably for the seventh zoom optical system, at least one positive lens in the third group should satisfy the following condition.

$$0.1 < HH3/\phi 3 < 8 \quad \dots (4G)$$

Here, HH3 is the principal point spacing (mm) of the positive lens in the third group, and  $\phi 3$  is the refracting power of the positive lens in the third group.

The advantage of, and the requirement for, the above

arrangement is now explained. By increasing the power of the positive lens located in the third group, the distance of movement of the third group can be shortened. This also results in a decrease in the whole length of the lens system. With the conventional lens processing, however, there is much difficulty in balancing cost savings against size reductions, as detailed in connection with the first zoom optical system.

However, if the positive lens is formed as a one-piece lens, it is then unnecessary to form it larger than the necessary outer diameter. The satisfaction of condition (4G) enables large power to be achieved with a thin lens and, hence, further size reductions to be obtained.

As the lower limit of 0.1 to condition (4G) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has difficulty in keeping the optical performance intact. As the upper limit of 8 is exceeded, the power becomes small relative to the principal point spacing and, hence, the amount of movement of the second group can never be reduced, resulting in an increase in the whole length of the lens system.

It is more preferable to satisfy the following condition (4G-2). In this case, the reduction in the whole length of the lens system can be reconciled with slimming down each lens.

$$0.5 < HH3/\phi_3 < 5 \quad \dots (4G-2)$$

It is even more preferable to satisfy the following condition (4G-3). In this case, it is easier to offer a sensible compromise between the reduction in the whole  
 5 length of the lens system and slimming down each lens.

$$1 < HH3/\phi_3 < 2.5 \quad \dots (4G-3)$$

Preferably for the seventh zoom optical system, at least one one-piece lens in the third group should have at least one aspheric surface.

10 The advantage of, and the requirement for, the above arrangement is now explained. In the seventh optical system, the diameter of a light beam is enlarged by the second group having negative refracting power, and so at the wide-angle end, the diameter of a light beam through  
 15 the third group becomes large. With this in mind, at least one aspheric surface is introduced in the third group. As a result, fluctuations with zooming of various aberrations such as spherical aberration and coma can be well corrected with a more reduced number of lenses.  
 20 Therefore, the optical system can be slimmed down at low cost.

Preferably for the seventh zoom optical system, the fourth group should comprise at least one one-piece lens.

The advantage of, and the requirement for, the above  
 25 arrangement is the same as in the fourth zoom optical system.

Preferably for the seventh zoom optical system, at



least one of the one-piece lenses in the fourth group should be a positive lens having positive refracting power.

The advantage of, and the requirement for, the above arrangement is the same as in the fifth zoom optical  
5 system.

Preferably for the seventh zoom optical system, at least one positive lens in the fourth group should satisfy the following condition.

$$0.1 < HH4/\phi4 < 10 \quad \dots (5G)$$

10 Here, HH4 is the principal point spacing (mm) of the positive lens in the fourth group and  $\phi4$  is the refracting power of the positive lens in the fourth group.

The advantage of, and the requirement for, the above arrangement is the same as set forth with reference to the  
15 fifth zoom optical system.

As the lower limit of 0.1 to condition (5G) is not reached, the power becomes too large relative to the principal point spacing. This does not only result in an increased sensitivity to decentration, but also has  
20 difficulty in keeping the optical performance intact. Exceeding the upper limit of 10 is not preferable, because the power becomes small relative to the principal point spacing, and so the exit pupil position at the wide-angle end comes close to the image plane. As a result, it is  
25 impossible to ensure telecentric capability on the image side.

It is more preferable to satisfy the following

condition (5G-2). In this case, the reduction in the whole length of the lens system and the telecentric capability on the image side can be reconciled with slimming down each lens.

5                                       $0.5 < HH4/\phi 4 < 7$                                       ... (5G-2)

It is even more preferable to satisfy the following condition (5G-3). In this case, it is easier to reconcile the reduction in the whole length of the lens system and telecentric capability on the image side with slimming  
10 down each lens.

$1 < HH4/\phi 4 < 4$                                       ... (5G-3)

Preferably for the seventh zoom optical system, at least one one-piece lens in the fourth group should have at least one aspheric surface.

15                      The advantage of, and the requirement for, the above arrangement is now explained. At the wide-angle end, light rays through the fourth group gain height. Therefore, if at least one aspheric surface is included in the fourth group, off-axis aberrations such as distortion  
20 and astigmatism can then be well corrected with a more reduced number of lenses. As a result, the optical system can be slimmed down at low cost.

Preferably, the electronic system of the invention should comprise any one of the zoom optical systems as  
25 described above, and an electronic image pickup device located on an image side thereof.

The above zoom optical systems are each of smaller

size and lower cost than ever before. Therefore, if any one of them is mounted in the form of an imaging optical system on an electronic system, the size and cost of the electronic system can then be much more reduced. It is  
5 noted that the electronic system intended herein includes digital cameras, video cameras, digital video units, personal computers, mobile computers, cellular phone, personal digital assistants, etc.

Examples under the categories of the 1<sup>st</sup> to 7<sup>th</sup> zoom  
10 optical systems (zoom lenses) are now explained with reference to the accompanying drawings. For instance, Example 1 of the first zoom optical system is designated as "Example 1-1", and Example 2 of the fifth zoom optical system as "Example 5-2". Lens section diagrams and  
15 aberration diagrams for each lens are provided. Each lens section diagram is taken along the optical axis of each zoom optical system at the wide-angle end (a), in an intermediate setting (b) and the telephoto end (c) upon focusing on an infinite object point. Throughout the  
20 drawings, G1 is the first lens group; G2 is the second lens group; G3 is the third lens group; G4 is the fourth lens group; S is an aperture stop; F is plane-parallel plate group such as a near infrared cut filter, a low-pass filter and a cover glass for the electronic image pickup  
25 device; and I is an image plane. The aberration diagrams are provided for spherical aberration, astigmatism, chromatic aberration of magnification and distortion at the wide-angle end (a), in the intermediate setting (b)

and at the telephoto end (c) upon focusing on an infinite object point. In these aberration diagrams, "FIY" stands for an image height.

- (1) Zoom optical system wherein the first group is  
5 a negative lens group and the second group is a  
positive lens group

Examples 1-1 and 1-2 of the first zoom optical system (zoom lens) are now explained with reference to the drawings. Figs. 7 and 8 are illustrative in lens section  
10 along the optical axes of Examples 1-1 and 1-2 at the wide-angle ends (a), in intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object point. Figs. 9 and 10 are aberration diagrams for spherical aberration, astigmatism and  
15 chromatic aberration of magnification of Examples 1-1 and 1-2 at the wide-angle ends (a), in the intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object point.

#### Example 1-1

20 Fig. 7 is illustrative in section of the zoom optical system of Example 1-1, which is made up of, in order from its object side, a first lens group G1, an aperture stop S and a second lens group G2. Upon zooming from the wide-angle end to the telephoto end of the  
25 optical system, the first lens group G1 moves in a concave locus toward the object side and is located in the same position at the telephoto end as at the wide-angle end,

and the second lens group G2 moves in unison with the aperture stop S toward the object side.

The first lens group G1 has generally negative power, and is composed of, in order from its object side, a  
5 double-concave negative lens and a doublet consisting of a double-convex positive lens and a double-concave negative lens. Two aspheric surfaces are used at both surfaces of the double-concave negative lens.

The second lens group G2 has generally positive  
10 power, and is composed of, in order from its object side, a double-convex positive lens and a doublet consisting of a double-convex positive lens and a double-concave negative lens. Two aspheric surfaces are applied: one at the surface nearest to the object side and another at the  
15 surface nearest to the image side of the second lens group G2.

The lenses that form the zoom optical system of this example are all one-piece lenses except the double-concave negative lens on the image side of the second lens group  
20 G2. Each one-piece lens has been fabricated by the process shown in Fig. 1.

One exemplary one-piece lens 10 is shown in Fig. 11. This one-piece lens is used on the zoom optical system of this example. Fig. 11 is a sectional view of the doublet  
25 in the second lens group G2, wherein a double-convex positive lens on the object side is integrated with the doublet into the one-piece lens 10, and a double-concave negative lens is cemented to its image side. The second

lens blank 12 has a thickness of 0.3 mm. Although not shown in Fig. 11, the second lens blank 12 could be processed simultaneously with the formation of a hole or an irregular pattern.

## 5 Example 1-2

Fig. 8 is illustrative in section of the zoom optical system of Example 1-2, which is made up of, in order from its object side, a first lens group G1, an aperture stop S and a second lens group G2. Upon zooming  
10 from the wide-angle end to the telephoto end of the optical system, the first lens group G1 moves in a concave locus toward the object side of the optical system and is located in much the same position at the telephoto end as at the wide-angle end, and the second lens group G2 moves  
15 in unison with the aperture stop S toward the object side.

The first lens group has generally negative power, and is composed of, in order from its object side, a double-concave negative lens and a positive meniscus lens concave on its object side. One aspheric surface is  
20 applied to the object-side surface of the double-concave negative lens.

The second lens group G2 has generally positive power, and is composed of, in order from its object side, a doublet consisting of a double-convex positive lens and  
25 a negative meniscus lens convex on its object side and a negative meniscus lens convex on its image side. Two aspheric surfaces are used: one at the surface nearest to the object side and another at the surface nearest to the

image side of the second lens group G2.

The lenses that form the zoom optical system of this example are all one-piece lenses except the negative meniscus lens on the object side of the second lens group G2. Each one-piece lens has been fabricated by the process shown in Fig. 3.

One exemplary one-piece lens 10 used herein is shown in Figs. 12 and 13. Fig. 12 is illustrative in section of the doublet in the second lens group G2. In this doublet, the object-side double-convex positive lens is formed as the one-piece lens 10 with the negative meniscus lens cemented to the image side thereof. The second lens blank 12 is 0.25 mm in thickness. Fig. 13 is illustrative in section of the image-side lens in the second lens group G2. In this lens, the negative meniscus lens is formed as the one-piece lens 10. The second lens blank 12 is 1.5 mm in thickness. Although not shown in Figs. 12 and 13, the second lens blank 12 could be processed simultaneously with the provision of a hole or an irregular pattern (see Fig. 3).

Numerical data on each of the above examples will be enumerated later.

(2) Zoom optical system wherein the first group is a positive lens group and the second group is a negative lens group

Examples 2-1 and 2-2 of the second zoom optical system (zoom lens) are now explained with reference to the drawings. Figs. 14 and 15 are illustrative in lens

section along the optical axes of Examples 2-1 and 2-2 at the wide-angle ends (a), in intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object point. Figs. 16 and 17 are aberration diagrams for spherical aberration, astigmatism and chromatic aberration of magnification of Examples 2-1 and 2-2 at the wide-angle ends (a), in the intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object point.

#### Example 2-1

Fig. 14 is illustrative of the zoom optical system of Example 2-1, which is made up of, in order from its object side, an aperture stop S, a first lens group G1 and a second lens group G2. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens group G1 and the aperture stop S move in unison toward the object side, and the second lens group G2 moves toward the object side with a decreasing space between it and the first lens group G1.

The first lens group G1 has generally positive power, and is composed of, in order from its object side, a positive meniscus lens concave on its object side, a negative meniscus lens convex on its object side and a double-convex positive lens. Two aspheric surfaces are applied to both surfaces of the positive meniscus lens, and one aspheric surface is applied to the image-side surface of the double-convex positive lens.

The second lens group G2 has generally negative



power, and is composed of, in order from its object side,  
a positive meniscus lens concave on its object side and a  
double-concave negative lens. One aspheric surface is  
applied to the object-side surface of the double-concave  
5 negative lens.

The lenses that form the zoom optical system of the  
example are all one-piece lenses except the image-side  
negative meniscus lens in the first lens group G1. Each  
one-piece lens has been fabricated by the process shown in  
10 Fig. 3.

One exemplary one-piece lens 10 used herein is shown  
in Fig. 19. Fig. 19 is illustrative in section of the  
doublet in the first lens group G1, wherein the image-side  
double-convex positive lens is configured as the one-piece  
15 lens 10, with the negative meniscus lens cemented to the  
object side thereof. The second lens blank 12 is 0.2 mm  
in thickness. Although not shown in fig. 19, the second  
lens blank 12 could be processed simultaneously with the  
provision of a hole or an irregular pattern (see Fig. 3).

20 Numerical data on each example will be given later.

(3) Zoom optical system wherein the first group is a  
negative lens group, the second group is a positive  
lens group and the third group is a positive lens  
group

25 Examples 3-1 and 3-2 of the third zoom optical  
system (zoom lens) are now explained with reference to the  
drawings. Figs. 20 and 21 are illustrative in lens  
section along the optical axes of Examples 3-1 and 3-2 at

the wide-angle ends (a), in intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object point. Figs. 20 and 21 are aberration diagrams for spherical aberration, astigmatism and

5 chromatic aberration of magnification of Examples 3-1 and 3-2 at the wide-angle ends (a), in the intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object point.

#### Example 3-1

10 Fig. 20 is illustrative of the zoom optical system of Example 3-1, which is made up of, in order from its object side, a first lens group G1, an aperture stop S, a second lens group G2 and a third lens group G3. Upon zooming from the wide-angle end to the telephoto end of  
15 the optical system, the first lens group G1 moves in a concave locus toward the object side and is located in the same position at the telephoto end as at the wide-angle end, and the second lens group moves in unison with the aperture stop S toward the object side. The third lens  
20 group G3 moves toward the image side of the optical system.

The first lens group G1 has generally negative power, and is composed of, in order from its object side, a negative meniscus lens convex on its object side and a positive meniscus lens concave on its image side. One  
25 spherical surface is applied to the image-side surface of the negative meniscus lens.

The second lens group G2 has generally positive power, and is composed of, in order from its object side,

a double-convex positive lens, a double-concave negative lens and a double-convex positive lens. One aspheric surface is applied to the object-side surface of the double-convex positive lens nearest to the object side.

5           The third lens group G3 has positive power, and is composed of a positive meniscus lens concave on its image side. One aspheric surface is applied to the object-side surface of the positive meniscus lens.

          The lenses that form the zoom optical system used  
10   herein are all one-piece lenses except the object-side negative meniscus lens in the first lens group G1. Each one-piece lens has been fabricated by the process shown in Fig. 1.

          One exemplary one-piece lens 10 used herein is shown  
15   in Fig. 24. Fig. 24 is illustrative in section of the image-side positive meniscus lens in the first lens group G1. In this lens, the positive meniscus lens is configured as a one-piece lens. The second lens blank 12 is 0.45 mm in thickness. Although not depicted in Fig. 24,  
20   the second lens blank 12 could be processed simultaneously with the provision of a hole or an irregular pattern.

#### Example 3-2

          Fig. 21 is illustrative of the zoom optical system of Example 3-2, which is made up of, in order from its  
25   object side, a first lens group G1, an aperture stop S, a second lens group G2 and a third lens group G3. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens group G1 moves in a

concave locus toward the object side, and is located in much the same position at the telephoto end as at the wide-angle end, and the second lens group G2 moves in unison with the aperture stop S toward the object side.

5 The third lens group G3 remains fixed.

The first lens group G1 has generally negative power, and is composed of a doublet consisting of a double-concave negative lens and a positive meniscus lens concave on its image side. One aspheric surface is applied to the object-side surface of the double-concave negative lens.

The second lens group G2 has generally positive power, and is composed of, in order from its object side, a double-convex positive lens and a doublet consisting of a double-convex positive lens and a double-concave negative lens. One aspheric surface is applied to the object-side surface of the double-convex positive lens nearest to the object side.

The third lens group G3 has positive power, and is composed of a positive meniscus lens concave on its object side. One aspheric surface is applied to the image-side surface of the positive meniscus lens.

The lenses that form the zoom optical system of the example are all one-piece lenses except the double-concave negative lens in the second lens group G2. Each one-piece lens has been fabricated by the process shown in Fig. 3.

One exemplary one-piece lens 10 used herein is depicted in Fig. 25. Fig. 25 is illustrative in section of the doublet in the second lens group G2, wherein the

object-side double-convex positive lens is configured as the one-piece lens 10, with the double-concave negative lens cemented to the image side thereof. The second lens blank 12 has a thickness of 0.3 mm. Although not shown in  
5 Fig. 25, the second lens blank 12 could be processed simultaneously with the provision of a hole or an irregular pattern (see Fig. 3).

Numerical data on each example will be set out later.

(4) Zoom optical system wherein the first group is a  
10 negative lens group, the second group is a positive lens group, the third group is a positive lens group and the fourth group is a negative lens group

Examples 4-1 and 4-2 of the fourth zoom optical system (zoom lens) are now explained with reference to the  
15 drawings. Figs. 26 and 27 are illustrative in lens section along the optical axes of Examples 4-1 and 4-2 at the wide-angle ends (a), in intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object point. Figs. 28 and 29 are aberration  
20 diagrams for spherical aberration, astigmatism, chromatic aberration of magnification and distortion of Examples 4-1 and 4-2 at the wide-angle ends (a), in the intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object point.

25 Example 4-1

Fig. 26 is illustrative of the zoom optical system of Example 4-1, which is made up of, in order from its object side, a first lens group G1, an aperture stop S, a

second lens group G2, a third lens group G3 and a fourth lens group G4. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens group G1 moves in a concave locus toward the object side and is located in much the same position at the telephoto end as at the wide-angle end; the second lens group G2 moves in unison with the aperture stop S toward the object side; and the third and fourth lens groups G3 and G4 remain fixed.

10       The first lens group G1 has generally negative power, and is composed of, in order from its object side, a double-concave negative lens and a positive meniscus lens concave on its image side. One aspheric surface is applied to the image-side surface of the double-concave  
15       negative lens.

      The second lens group G2 has generally positive power, and is composed of, in order from its object side, a double-convex positive lens and a doublet consisting of a double-convex positive lens and a double-concave  
20       negative lens. Two aspheric surfaces are used: one at the object-side surface of the double-convex positive lens that is a single lens, and another at the surface of the doublet nearest to its object side.

      The third lens group G3 has positive power, and  
25       consists of a double-convex positive lens. The third lens group G3 moves in the optical axis direction upon focusing alone.

      The fourth lens group G4 has negative power, and

consists of a negative meniscus lens convex on its image side. One aspheric surface is applied to the image-side surface of the negative meniscus lens.

5 The lenses that form the zoom optical system of the example are all one-piece lenses. Each one-piece lens has been fabricated by the process shown in Fig. 1.

One exemplary one-piece lens 10 used herein is shown in Fig. 30. Fig. 30 is illustrative in section of the second lens as counted from the object side of the first lens group G1, wherein the positive meniscus lens is configured as the one-piece lens. The second lens blank 12 is 0.4 mm in thickness. Although not shown in Fig. 30, the second lens blank 12 could be processed simultaneously with the provision of a hole or an irregular pattern.

#### 15 Example 4-2

Fig. 27 is illustrative of the zoom optical system of the example, which is made up of, in order from its object side, a first lens group G1, a second lens group G2, a third lens group G3 and a fourth lens group G4. An aperture stop S is interposed between the first lens and the second lens in the second lens group G1 in an integration fashion with them. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens group G1 moves in a concave locus toward the object side and is located in much the same position at the telephoto end as at the wide-angle end; the second lens group G2 moves in unison with the apertures stop S toward the object side; and the third and fourth lens

groups G3 and G4 remain stationary.

The first lens group G1 has generally negative power, and is composed of a doublet consisting of a double-concave negative lens and a positive meniscus lens concave  
5 on its image side.

The second lens group G2 has generally positive power, and is composed of, in order from its object side, a positive meniscus lens concave on its image side, an aperture stop S and a doublet consisting of a double-  
10 convex positive lens and a double-concave negative lens. Three aspheric surfaces are used: one at the object-side surface of the positive meniscus lens and two at the surfaces of the doublet nearest to its object and image sides.

15 The third lens group G3 has positive power, and consists of a positive meniscus lens convex on its image side. The third lens group G3 moves in the optical axis direction upon focusing alone.

The fourth lens group G4 has negative power, and  
20 consists of a negative meniscus lens convex on its image side. One aspheric surface is applied to the image-side surface of the negative meniscus lens.

The lenses that form the zoom optical system of the example are all one-piece lenses except the double-concave  
25 negative lens in the first lens group G1. Each one-piece lens has been fabricated by the process shown in Fig. 3.

One exemplary one-piece lens 10 used herein is shown in Fig. 31. Fig. 31 is illustrative in section of the



doublet in the first lens group G1. In this doublet, the image-side positive meniscus lens is configured as the one-piece lens 10, with the double-concave negative lens cemented to the object side thereof. The second lens  
5 blank 12 is 0.3 mm in thickness. Although not depicted in Fig. 31, the second lens blank 12 could be processed simultaneously with the provision of a hole or an irregular pattern (see Fig. 3).

Numerical data on each example will be set out later.  
10 (5) Zoom optical system wherein the first group is a negative lens group, the second group is a positive lens group, the third group is a negative lens group and the fourth group is a positive lens group

Examples 5-1 and 5-2 of the fifth zoom optical  
15 system (zoom lens) are now explained with reference to the drawings. Figs. 32 and 33 are illustrative in lens section along the optical axes of Examples 5-1 and 5-2 at the wide-angle ends (a), in intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on  
20 an infinite object point. Figs. 34 and 35 are aberration diagrams for spherical aberration, astigmatism, chromatic aberration of magnification and distortion of Examples 5-1 and 5-2 at the wide-angle ends (a), in the intermediate settings (b) and at the telephoto ends (c), respectively,  
25 upon focusing on an infinite object point.

#### Example 5-1

Fig. 32 is illustrative of the zoom optical system of this example, which is made up of, in order from its

object side, a first lens group G1, a second lens group G2, an aperture stop S, a third lens group G3 and a fourth lens group G4. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens  
5 group G1 remains fixed; the second lens group G2 moves in unison with the aperture stop S toward the object side; the third lens group G3 moves toward the object side while the space between it and the fourth lens group G4 first becomes narrow and then wide; and the fourth lens group G4  
10 remains fixed.

The first lens group G1 has generally negative power, and is composed of a doublet consisting of a double-concave negative lens and a positive meniscus lens concave on its image side. Three aspheric surfaces are used: one  
15 at the object-side surface of the double-convex positive lens, and two at the surfaces of the doublet nearest to its object and image sides.

The second lens group G2 has generally positive power, and is composed of, in order from its object side,  
20 a double-convex positive lens and a doublet consisting of a double-convex positive lens and a double-concave negative lens. Three aspheric surfaces are used: one at the object-side surface of the double-convex positive lens, and two at the surfaces of the doublet nearest to its  
25 object and image sides.

The third lens group G3 has negative power, and consists of a negative meniscus lens convex on its object side. One aspheric surface is applied to the image-side

surface of the negative meniscus lens.

The fourth lens group G4 has positive power, and consists of a positive meniscus lens concave on its object side. One aspheric surface is applied to the image-side  
5 surface of the positive meniscus lens.

The lenses that form the zoom optical system of this example are all one-piece lenses except the negative meniscus lens in the third lens group G3. Each one-piece lens has been fabricated by the process shown in Fig. 1.

10 One exemplary one-piece lens 10 used herein is depicted in Fig. 36. Fig. 36 is illustrative in section of the object-side double-convex positive lens in the second lens group G2. In this lens, the double-convex positive lens is configured as the one-piece lens. The  
15 second lens blank 12 is 0.4 mm in thickness. Although not shown in Fig. 36, the second lens blank 12 could be processed simultaneously with the provision of a hole or an irregular pattern.

#### Example 5-2

20 Fig. 33 is illustrative of the zoom optical system of this example, which is made up of, in order from its object side, a first lens group G1, a second lens group G2, an aperture stop S, a third lens group G3 and a fourth lens group G4. Upon zooming from the wide-angle end to  
25 the telephoto end of the optical system, the first lens group G1 remains fixed; the second lens group G2 moves in unison with the aperture stop S toward the object side; the third lens group G3 moves toward the object side while

the space between it and the fourth lens group G4 first becomes slightly narrow and then wide; and the fourth lens group G4 remains fixed.

5       The first lens group G1 has generally negative power, and is composed of a doublet consisting of a double-concave negative lens and a positive meniscus lens concave on its image side. Two aspheric surfaces are used at the surfaces of the doublet nearest to its object and image sides.

10       The second lens group G2 has generally positive power, and is composed of, in order from its object side, a double-convex positive lens and a doublet consisting of a double-convex positive lens and a double-concave negative lens. Three aspheric surfaces are used: one at  
15       the object-side surface of the double-convex positive lens that is a single lens, and two at the surfaces of the doublet nearest to its object and image sides.

20       The third lens group G3 has negative power, and consists of a double-concave negative lens. One aspheric surface is applied to the image-side surface of the double-convex positive lens.

25       The fourth lens group G4 has positive power, and consists of a double-convex positive lens. One aspheric surface is applied to the image-side surface of the double-convex positive lens.

The lenses that form the zoom optical system of this example are all one-piece lenses except the double-concave negative lens in the second lens group G2. Each one-piece

lens has been fabricated by the process shown in Fig. 3.

One exemplary one-piece lens 10 used herein is depicted in Fig. 37. Fig. 37 is illustrative in section of the doublet in the second lens group G2. In this doublet, the object-side double-convex positive lens is configured as the one-piece lens 10, with the double-concave negative lens cemented to the image side thereof. The second lens blank 12 has a thickness of 0.5 mm. Although not depicted in Fig. 37, the second lens blank 12 could be processed simultaneously with the provision of a hole or an irregular pattern (see Fig. 3).

Numerical data on each example will be given later.

(6) Zoom optical system wherein the first group is a negative lens group, the second group is a positive lens group, the third group is a positive lens group and the fourth group is a positive lens group

Examples 6-1, 6-2 and 6-3 of the sixth zoom optical system (zoom lens) are now explained with reference to the drawings. Figs. 38, 39 and 40 are illustrative in lens section along the optical axes of Examples 6-1, 6-2 and 6-3 at the wide-angle ends (a), in intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object point. Figs. 41, 42 and 43 are aberration diagrams for spherical aberration, astigmatism, chromatic aberration of magnification and distortion of Examples 6-1, 6-2 and 6-3 at the wide-angle ends (a), in the intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object

point.

#### Example 6-1

Fig. 38 is illustrative of the zoom optical system of this example, which is made up of, in order from its object side, a first lens group G1, an aperture stop S, a second lens group G2, a third lens group G3 and a fourth lens group G4. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens group G1 moves in a concave locust toward the object side and is located in much the same position at the telephoto end as at the wide-angle end. The second lens group G2 moves in unison with the aperture stop S toward the object side. The third lens group moves slightly toward the object side. The fourth lens group G4 moves in a convex locus slightly toward the object side, and is located nearer to the image side of the optical system at the telephoto end than at the wide-angle end.

The first lens group G1 has generally negative power, and is composed of, in order from its object side, a double-concave negative lens and a positive meniscus lens concave on its image side. One aspheric surface is applied to the image-side surface of the double-concave negative lens.

The second lens group G2 has generally positive power, and is composed of, in order from its object side, a double-convex positive lens and a doublet consisting of a double-convex positive lens and a double-concave negative lens. Two aspheric surfaces are used: one at the

object-side surface of the double-convex positive lens and one at the surface of the doublet nearest to its object side.

The third lens group G3 has positive power, and  
5 consists of a positive meniscus lens concave on its image side. One aspheric surface is applied to the image-side surface of the positive meniscus lens.

The fourth lens group G4 has positive power, and consists of a plano-convex positive lens convex on its  
10 image side. One aspheric surface is applied to the image-side surface of the plano-convex positive lens.

The lenses that form the zoom optical system of this example are all one-piece lenses except the double-concave negative lens in the second lens group G2. Each one-piece  
15 lens has been fabricated by the process shown in Fig. 1.

One exemplary one-piece lens 10 used herein is shown in Fig. 44. Fig. 44 is illustrative in section of the doublet in the second lens group G2. In this doublet, the object-side double-convex positive lens is configured as  
20 the one-piece lens 10, with the double-concave negative lens cemented to the image side thereof. The second lens blank 12 is 0.35 mm in thickness. Although not depicted in Fig. 44, the second lens blank 12 could be processed simultaneously with the provision of a hole or an  
25 irregular pattern.

#### Example 6-2

Fig. 39 is illustrative of the zoom optical system of this example, which is made up of, in order from its

object side, a first lens group G1, an aperture stop S, a second lens group G2, a third lens group G3 and a fourth lens group G4. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens  
5 group G1 moves in a concave locust toward the object side and is located in much the same position at the telephoto end as at the wide-angle end. The second lens group G2 moves in unison with the aperture stop S toward the object side. The third lens group G3 moves toward the object  
10 side while the space between it and the second lens group G2 becomes wide. The fourth lens group G4 moves in a convex locus toward the object side and is positioned nearer to the image side of the optical system at the telephoto end than at the wide-angle end.

15 The first lens group G1 has generally negative power, and is composed of, in order from its object side, a plane-concave negative lens concave on its image side and a positive meniscus lens concave on its image side. One aspheric surface is applied to the image-side surface of  
20 the plano-concave negative lens.

The second lens group G2 has generally positive power, and is composed of, in order from its object side, a double-convex positive lens and a doublet consisting of a double-convex positive lens and a double-concave  
25 negative lens. Two aspheric surfaces are used: one at the object-side surface of the object-side double-convex positive lens and one at the surface of the doublet nearest to its object side.



The third lens group G3 has positive power, and consists of a positive meniscus lens concave on its image side. One aspheric surface is applied to the image-side surface of the positive meniscus lens.

5       The fourth lens group G4 has positive power, and consists of a positive meniscus lens concave on its object side. One aspheric surface is applied to the image-side surface of the positive meniscus lens.

The lenses that form the zoom optical system of this  
10       example are all one-piece lenses that have been fabricated by the process shown in Fig. 3.

One exemplary one-piece lens 10 used herein is shown in Fig. 45. Fig. 45 is illustrative in section of the positive meniscus lens in the first lens group G1. In  
15       this lens, the positive meniscus lens is configured as the one-piece lens 10. The second lens blank 12 is 0.5 mm in thickness. Although not depicted in Fig. 45, the second lens blank 12 could be processed simultaneously with the provision of a hole or an irregular pattern (see Fig. 3).

20       Example 6-3

Fig. 40 is illustrative of the zoom optical system of this example, which is made up of, in order from its object side, a first lens group G1, an aperture stop S, a second lens group G2, a third lens group G3 and a fourth  
25       lens group G4. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens group G1 moves in a concave locus toward the object side and is located in much the same position at the telephoto

end as at the wide-angle end. The second lens group G2 moves in unison with the aperture stop S toward the object side. The third lens group G3 moves in a concave locus toward the object side and is positioned nearer to the object side at the telephoto end than at the wide-angle end. The fourth lens group G4 remains fixed.

The first lens group G1 has generally negative power, and is composed of, in order from its object side, a double-concave negative lens and a positive meniscus lens concave on its image side. One aspheric surface is applied to the image-side surface of the double-concave negative lens.

The second lens group G2 has generally positive power, and is composed of, in order from its object side, a double-convex positive lens and a doublet consisting of a double-convex positive lens and a double-concave negative lens. Two aspheric surfaces are used: one at the object-side surface of the object-side double-convex positive lens and one at the surface of the doublet nearest to its object side.

The third lens group G3 has positive power, and consists of a positive meniscus lens concave on its image side. One aspheric surface is applied to the image-side surface of the positive meniscus lens.

The fourth lens group G4 has positive power, and consist of a positive meniscus lens concave on its image side. One aspheric surface is applied to the image-side surface of the positive meniscus lens.

The lenses that form the zoom optical system of this example are all one-piece lenses except the double-concave negative lens in the second lens group G2. Each one-piece lens has been fabricated by the process shown in Fig. 5.

5        One exemplary one-piece lens 10 used herein is shown in Fig. 46. Fig. 46 is illustrative in section of the doublet in the second lens group G2. In this doublet, the object-side double-convex positive lens is configured as the one-piece lens 10, with the double-concave negative  
10    lens cemented to the image side thereof. The second lens blank 12 is 0.3 mm in thickness. Although not depicted in Fig. 46, the second lens blank 12 could be processed simultaneously with the formation of a hole or an irregular pattern (see Fig. 3).

15        Numerical data on each example will be given later.

(7) Zoom optical system wherein the first group is a positive lens, the second group is a negative lens group, the third group is a positive lens group and the fourth group is a positive lens group

20        Examples 7-1, 7-2 and 7-3 of the sixth zoom optical system (zoom lens) are now explained with reference to the drawings. Figs. 47, 48 and 49 are illustrative in lens section along the optical axes of Examples 7-1, 7-2 and 7-3 at the wide-angle ends (a), in intermediate settings (b)  
25    and at the telephoto ends (c), respectively, upon focusing on an infinite object point. Figs. 50, 51 and 52 are aberration diagrams for spherical aberration, astigmatism, chromatic aberration of magnification and distortion of

Examples 7-1, 7-2 and 7-3 at the wide-angle ends (a), in the intermediate settings (b) and at the telephoto ends (c), respectively, upon focusing on an infinite object point.

#### 5 Example 7-1

Fig. 47 is illustrative of the zoom optical system of this example, which is made up of, in order from its object side, a first lens group G1, a second lens group G2, an aperture stop S, a third lens group G3 and a fourth  
10 lens group G4. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens group G1 remains fixed; the second lens group G2 moves toward the image side of the optical system; the aperture stop S moves toward the object side; and both the third  
15 and fourth lens groups G3 and G4 move toward the object side. In the meantime, the third and fourth lens groups G3 and G4 move while their space becomes wide.

The first lens group G1 has generally positive power, and consists of a double-convex positive lens. One  
20 aspheric surface is applied to the object-side surface of the double-convex positive lens.

The second lens group G2 has generally negative power, and is composed of a doublet consisting of a double-concave negative lens and a positive meniscus lens  
25 concave on its image side. One aspheric surface is applied to the surface of the doublet nearest to its object side.

The third lens group G3 has positive power, and is

composed of, in order from its object side, a double-convex positive lens and a double-concave negative lens. Two aspheric surfaces are used: one at the object-side surface of the double-convex positive lens and another at  
5 the image-side surface of the double-concave negative lens.

The fourth lens group G4 has positive power, and consists of a double-convex positive lens. One aspheric surface is applied to the object-side surface of the double-convex positive lens.

10 The lenses that form the zoom optical system of this example are all one-piece lenses that have been fabricated by the process illustrated in Fig. 1.

One exemplary one-piece lens 10 used herein is shown in Fig. 53. Fig. 53 is illustrative in section of the  
15 double-convex positive lens in the fourth lens group G4, which is configured as a one-piece lens. The second lens blank 12 is 0.4 mm in thickness. Although not shown in Fig. 53, the second lens blank 12 could be processed simultaneously with the formation of a hole or an  
20 irregular pattern.

#### Example 7-2

Fig. 48 is illustrative of the zoom optical system of this example, which is made up of, in order from its object side, a first lens group G1, a second lens group G2,  
25 an aperture stop S, a third lens group G3 and a fourth lens group G4. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens group G1 remains fixed; the second lens group G2 moves

toward the image side of the optical system; the aperture stop S moves toward the object side; and both the third and fourth lens groups G3 and G4 move toward the object side while their space becomes wide.

5           The first lens group G1 generally positive power, and consists of a double-convex positive lens. One aspheric surface is applied to the object-side surface of the double-convex positive lens.

          The second lens group G2 has generally negative  
10 power, and consists of a double-concave negative lens and a positive meniscus lens concave on its image side. One aspheric surface is applied to the object-side surface of the double-concave negative lens.

          The third lens group G3 has positive power, and is  
15 composed of, in order from its object side, a double-convex positive lens and a double-concave negative lens. Two aspheric surfaces are used: one at the object-side surface of the double-convex positive lens and another at the image-side surface of the double-concave negative lens.

20           The fourth lens group G4 has positive power, and consists of a positive meniscus lens concave on its image side. One aspheric surface is applied to the object-side surface of the positive meniscus lens.

          The lenses that form the zoom optical system of this  
25 example are all one-piece lenses that have been fabricated by the process shown in Fig. 3.

          Exemplary one-piece lenses used herein are shown in Figs. 54 and 55. Fig. 54 is illustrative in section of

the positive meniscus lens in the second lens group G2, which is configured as the one-piece lens 10. The second lens blank 12 has a thickness of 0.4 mm. Fig. 55 is illustrative in section of the double-concave negative lens in the third lens group G3, which is configured as a one-piece lens. The second lens blank 12 is 1.2 mm in thickness. Although not shown in Figs. 54 and 55, the second lens blank 12 could be processed simultaneously with the formation of a hole or an irregular pattern (see Fig. 3).

#### Example 7-3

Fig. 49 is illustrative of the zoom optical system of this example, which is made up of, in order from its object side, a first lens group G1, a second lens group G2, an aperture stop S, a third lens group G3 and a fourth lens group G4. Upon zooming from the wide-angle end to the telephoto end of the optical system, the first lens group G1 remains fixed; the second lens group G2 moves toward the image side of the optical system; the aperture stop S remains fixed; the third lens group G3 moves toward the object side; and the fourth lens group G4 moves in a convex locus toward the object side. It is here noted that the fourth lens group G4 is positioned nearer to the image side at the telephoto end than at the wide-angle end.

The first lens group G1 has generally positive power, and consists of a double-convex positive lens. One aspheric surface is applied to the object-side surface of the double-convex positive lens.

The second lens group G2 has generally negative power, and is composed of, in order from its object side, a double-convex positive lens and a positive meniscus lens concave on its image side. One aspheric surface is  
5 applied to the object-side surface of the double-concave negative lens.

The third lens group G3 has positive power, and is composed of, in order from its object side, a double-convex positive lens and a double-concave negative lens.  
10 Two aspheric surfaces are used: one at the object-side surface of the double-convex positive lens and another at the image-side surface of the double-concave negative lens.

The fourth lens group G4 has positive power, and consists of a meniscus lens concave on its image side.  
15 One aspheric surface is applied to the object-side surface of the positive meniscus lens.

The lenses that form the zoom optical system of this example are all one-piece lenses that have been fabricated by the process illustrated in Fig. 5.

20 One exemplary one-piece lens 10 used herein is illustrated in Fig. 56. Fig. 56 is illustrative of the positive meniscus lens in the fourth lens group G4, which is configured as a one-piece lens. The second lens blank 12 is 0.3 mm in thickness. Although not shown in Fig. 56,  
25 the second lens blank 12 could be processed simultaneously with the formation of a hole or an irregular pattern (see Fig. 3).

The numerical data on each example are now set out.



However, it is noted that the symbols used hereinafter but not hereinbefore have the following meanings.

f: focal length of the zoom optical system,

$f_{NO}$ : F-number,

5  $\omega$ : half angle of view,

WE: wide-angle end,

ST: intermediate setting,

TE: telephoto end,

$r_1, r_2, \dots$ : radius of curvature of each lens surface,

10  $d_1, d_2, \dots$ : space between adjacent lens surfaces,

$n_{d1}, n_{d2}, \dots$ : d-line refractive index of each lens,

and

$v_{d1}, v_{d2}, \dots$ : Abbe constant of each lens.

Note that the aspheric shape is given by the  
15 following formula, provided that x is an optical axis  
where the direction of travel of light is taken as  
positive, and y is a direction orthogonal to the optical  
axis.

$$x = (y^2/r) / [1 + \{1 - (K+1) (y/r)^2\}^{1/2}]$$

20  $+A_4y^4+A_6y^6+A_8y^8+A_{10}y^{10}$

Here r is a paraxial radius of curvature, K is a conical coefficient, and  $A_4, A_6, A_8$  and  $A_{10}$  are the 4<sup>th</sup> -, 6<sup>th</sup> -, 8<sup>th</sup> - and 10<sup>th</sup> -order aspheric coefficients, respectively.

### Example 1 - 1

|            |                    |            |            |            |         |              |       |
|------------|--------------------|------------|------------|------------|---------|--------------|-------|
| $r_1 =$    | -41.781 (Aspheric) | $d_1 =$    | 0.60       | $n_{d1} =$ | 1.80610 | $\nu_{d1} =$ | 40.92 |
| $r_2 =$    | 3.177 (Aspheric)   | $d_2 =$    | 0.66       |            |         |              |       |
| $r_3 =$    | 6.332              | $d_3 =$    | 0.62       | $n_{d2} =$ | 1.84666 | $\nu_{d2} =$ | 23.78 |
| $r_4 =$    | 24.596             | $d_4 =$    | (Variable) |            |         |              |       |
| $r_5 =$    | $\infty$ (Stop)    | $d_5 =$    | 0.10       |            |         |              |       |
| $r_6 =$    | 2.662 (Aspheric)   | $d_6 =$    | 0.95       | $n_{d3} =$ | 1.51633 | $\nu_{d3} =$ | 64.14 |
| $r_7 =$    | -6.827             | $d_7 =$    | 0.10       |            |         |              |       |
| $r_8 =$    | 9.099              | $d_8 =$    | 0.86       | $n_{d4} =$ | 1.80610 | $\nu_{d4} =$ | 40.92 |
| $r_9 =$    | -2.887             | $d_9 =$    | 0.61       | $n_{d5} =$ | 1.68893 | $\nu_{d5} =$ | 31.07 |
| $r_{10} =$ | 3.039 (Aspheric)   | $d_{10} =$ | (Variable) |            |         |              |       |
| $r_{11} =$ | $\infty$           | $d_{11} =$ | 0.50       | $n_{d6} =$ | 1.51633 | $\nu_{d6} =$ | 64.14 |
| $r_{12} =$ | $\infty$           |            |            |            |         |              |       |

### Aspherical Coefficients

1st surface

$$K = 298.089$$

$$A_4 = -1.32975 \times 10^{-2}$$

$$A_6 = 2.40059 \times 10^{-3}$$

$$A_8 = -1.12956 \times 10^{-4}$$

$$A_{10} = 0$$

2nd surface

$$K = -6.673$$

$$A_4 = 7.26462 \times 10^{-3}$$

$$A_6 = -2.67280 \times 10^{-3}$$

$$A_8 = 1.15842 \times 10^{-3}$$

$$A_{10} = -1.24655 \times 10^{-4}$$

6th surface

$$K = -1.680$$

$$A_4 = 3.59073 \times 10^{-3}$$

$$A_6 = -9.37097 \times 10^{-4}$$

$$A_8 = 1.54936 \times 10^{-4}$$

$$A_{10} = -3.54681 \times 10^{-5}$$

10th surface

$$K = 1.840$$

$$A_4 = 6.69764 \times 10^{-3}$$

$$A_6 = 0$$

$$A_8 = 0$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|                 | WE   | ST   | TE   |
|-----------------|------|------|------|
| f (mm)          | 4.4  | 6.23 | 8.78 |
| F <sub>NO</sub> | 2.8  | 3.3  | 4.1  |
| $\omega$ (°)    | 33.2 | 22.5 | 15.9 |
| d <sub>4</sub>  | 3.16 | 1.38 | 0.14 |
| d <sub>10</sub> | 4.24 | 5.47 | 7.26 |

Example 1-2

|                   |                    |                   |            |                   |         |              |       |
|-------------------|--------------------|-------------------|------------|-------------------|---------|--------------|-------|
| r <sub>1</sub> =  | -20.127 (Aspheric) | d <sub>1</sub> =  | 0.60       | n <sub>d1</sub> = | 1.67790 | $\nu_{d1}$ = | 55.34 |
| r <sub>2</sub> =  | 2.853              | d <sub>2</sub> =  | 1.23       |                   |         |              |       |
| r <sub>3</sub> =  | 4.097              | d <sub>3</sub> =  | 0.72       | n <sub>d2</sub> = | 1.84666 | $\nu_{d2}$ = | 23.78 |
| r <sub>4</sub> =  | 5.809              | d <sub>4</sub> =  | (Variable) |                   |         |              |       |
| r <sub>5</sub> =  | $\infty$ (Stop)    | d <sub>5</sub> =  | 0.10       |                   |         |              |       |
| r <sub>6</sub> =  | 2.549 (Aspheric)   | d <sub>6</sub> =  | 0.84       | n <sub>d3</sub> = | 1.69350 | $\nu_{d3}$ = | 53.21 |
| r <sub>7</sub> =  | -3.172             | d <sub>7</sub> =  | 0.60       |                   | 1.80518 |              | 25.42 |
| r <sub>8</sub> =  | -9.327             | d <sub>8</sub> =  | 1.04       | n <sub>d4</sub> = |         | $\nu_{d4}$ = |       |
| r <sub>9</sub> =  | -3.278             | d <sub>9</sub> =  | 0.60       | n <sub>d5</sub> = | 1.81474 | $\nu_{d5}$ = | 37.03 |
| r <sub>10</sub> = | -7.604 (Aspheric)  | d <sub>10</sub> = | (Variable) |                   |         |              |       |
| r <sub>11</sub> = | $\infty$           | d <sub>11</sub> = | 0.50       | n <sub>d6</sub> = | 1.51633 | $\nu_{d6}$ = | 64.14 |
| r <sub>12</sub> = | $\infty$           |                   |            |                   |         |              |       |

Aspherical Coefficients

1st surface

$$K = -228.497$$

$$A_4 = -1.41365 \times 10^{-3}$$

$$A_6 = 1.48862 \times 10^{-4}$$

$$A_8 = -4.35387 \times 10^{-6}$$

$$A_{10} = 0$$

6th surface

$$K = -0.176$$

$$A_4 = -4.34973 \times 10^{-4}$$

$$A_6 = 1.10461 \times 10^{-4}$$

$$A_8 = 2.52554 \times 10^{-4}$$

$$A_{10} = -1.39801 \times 10^{-4}$$

10th surface

$$K = -7.497$$

$$A_4 = 1.45179 \times 10^{-2}$$

$$A_6 = 7.85336 \times 10^{-4}$$

$$A_8 = 2.70499 \times 10^{-3}$$

$$A_{10} = -5.60770$$

Zooming Data ( $\infty$ )

|                       | WE   | ST   | TE   |
|-----------------------|------|------|------|
| f (mm)                | 3.0  | 5.2  | 9.0  |
| $F_{NO}$              | 3.5  | 4.5  | 6.3  |
| $\omega$ ( $^\circ$ ) | 50.4 | 26.7 | 15.6 |
| $d_4$                 | 5.05 | 1.96 | 0.19 |
| $d_{10}$              | 3.06 | 4.82 | 7.93 |

Example 2-1

$$\begin{array}{llll}
 r_1 = & \infty \text{ (Stop)} & d_1 = & 0.55 \\
 r_2 = & -2.158 \text{ (Aspheric)} & d_2 = & 0.69 \quad n_{d1} = 1.49700 \quad \nu_{d1} = 81.54 \\
 r_3 = & -2.071 \text{ (Aspheric)} & d_3 = & 0.10
 \end{array}$$

|            |                   |            |            |            |         |              |       |
|------------|-------------------|------------|------------|------------|---------|--------------|-------|
| $r_4 =$    | 10.989            | $d_4 =$    | 0.60       | $n_{d2} =$ | 1.84666 | $\nu_{d2} =$ | 23.78 |
| $r_5 =$    | 4.313             | $d_5 =$    | 0.12       |            |         |              |       |
| $r_6 =$    | 4.932             | $d_6 =$    | 1.16       | $n_{d3} =$ | 1.51633 | $\nu_{d3} =$ | 64.14 |
| $r_7 =$    | -2.401 (Aspheric) | $d_7 =$    | (Variable) |            |         |              |       |
| $r_8 =$    | -6.483            | $d_8 =$    | 0.62       | $n_{d4} =$ | 1.84666 | $\nu_{d4} =$ | 23.78 |
| $r_9 =$    | -3.958            | $d_9 =$    | 0.79       |            |         |              |       |
| $r_{10} =$ | -2.597 (Aspheric) | $d_{10} =$ | 0.60       | $n_{d5} =$ | 1.80610 | $\nu_{d5} =$ | 40.92 |
| $r_{11} =$ | 61.065            | $d_{11} =$ | (Variable) |            |         |              |       |
| $r_{12} =$ | $\infty$          | $d_{12} =$ | 0.50       | $n_{d6} =$ | 1.51633 | $\nu_{d6} =$ | 64.14 |
| $r_{13} =$ | $\infty$          |            |            |            |         |              |       |

#### Aspherical Coefficients

2nd surface

$K = 0.000$

$A_4 = -2.84390 \times 10^{-2}$

$A_6 = 9.11709 \times 10^{-3}$

$A_8 = 7.00659 \times 10^{-3}$

$A_{10} = 0$

3rd surface

$K = -0.894$

$A_4 = -6.81547 \times 10^{-3}$

$A_6 = 5.63263 \times 10^{-3}$

$A_8 = 5.81608 \times 10^{-3}$

$A_{10} = 0$

7th surface

$K = -0.359$

$A_4 = -4.65568 \times 10^{-3}$

$A_6 = -1.56716 \times 10^{-3}$

$A_8 = 1.86252 \times 10^{-4}$

$A_{10} = -7.14500 \times 10^{-5}$

10th surface

$$K = -4.566$$

$$A_4 = -2.78392 \times 10^{-2}$$

$$A_6 = 4.86515 \times 10^{-3}$$

$$A_8 = -5.40423 \times 10^{-4}$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|              | WE   | ST   | TE   |
|--------------|------|------|------|
| f (mm)       | 5.5  | 7.8  | 10.9 |
| $F_{NO}$     | 2.8  | 4.0  | 5.5  |
| $\omega$ (°) | 25.3 | 18.0 | 13.0 |
| $d_7$        | 1.71 | 0.76 | 0.10 |
| $d_{11}$     | 0.49 | 3.03 | 6.62 |

Example 2—2

|                           |                              |   |
|---------------------------|------------------------------|---|
| $r_1 = \infty$ (Stop)     | $d_1 = 0.61$                 |   |
| $r_2 = -2.480$ (Aspheric) | $d_2 = 0.60$                 | $n_{d1} = 1.49700 \quad \nu_{d1} = 81.54$ |
| $r_3 = -2.820$ (Aspheric) | $d_3 = 0.63$                 |   |
| $r_4 = 8.606$             | $d_4 = 0.60$                 | $n_{d2} = 1.68893 \quad \nu_{d2} = 31.07$ |
| $r_5 = 2.625$             | $d_5 = 1.24$                 | $n_{d3} = 1.58913 \quad \nu_{d3} = 61.14$ |
| $r_6 = -2.953$ (Aspheric) | $d_6 = \text{(Variable)}$    |   |
| $r_7 = -7.436$            | $d_7 = 0.63$                 | $n_{d4} = 1.84666 \quad \nu_{d4} = 23.78$ |
| $r_8 = -4.115$            | $d_8 = 0.73$                 |   |
| $r_9 = -2.736$ (Aspheric) | $d_9 = 0.60$                 | $n_{d5} = 1.80610 \quad \nu_{d5} = 40.92$ |
| $r_{10} = 26.678$         | $d_{10} = \text{(Variable)}$ |   |
| $r_{11} = \infty$         | $d_{11} = 0.50$              | $n_{d6} = 1.51633 \quad \nu_{d6} = 64.14$ |
| $r_{12} = \infty$         |                              |   |

Aspherical Coefficients

2nd surface

$$K = 0.000$$

$$A_4 = -5.18890 \times 10^{-3}$$

$$A_6 = 6.43068 \times 10^{-3}$$

$$A_8 = 2.08572 \times 10^{-3}$$

$$A_{10} = 0$$

3rd surface

$$K = -1.389$$

$$A_4 = -3.33499 \times 10^{-4}$$

$$A_6 = 5.27759 \times 10^{-3}$$

$$A_8 = 2.05797 \times 10^{-3}$$

$$A_{10} = 0$$

6th surface

$$K = -0.816$$

$$A_4 = -2.04253 \times 10^{-3}$$

$$A_6 = -1.18792 \times 10^{-3}$$

$$A_8 = 3.09456 \times 10^{-4}$$

$$A_{10} = -7.24211 \times 10^{-5}$$

9th surface

$$K = -3.385$$

$$A_4 = -1.65664 \times 10^{-2}$$

$$A_6 = 1.45807 \times 10^{-3}$$

$$A_8 = -8.20014 \times 10^{-5}$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|                 | WE   | ST   | TE    |
|-----------------|------|------|-------|
| f (mm)          | 5.5  | 7.78 | 10.96 |
| F <sub>NO</sub> | 2.8  | 4.0  | 5.6   |
| $\omega$ (°)    | 25.2 | 18.0 | 12.9  |
| d <sub>6</sub>  | 1.82 | 0.81 | 0.10  |
| d <sub>10</sub> | 0.39 | 2.92 | 6.55  |

Example 3-1

|            |                  |            |            |            |         |              |       |
|------------|------------------|------------|------------|------------|---------|--------------|-------|
| $r_1 =$    | 12.646           | $d_1 =$    | 0.60       | $n_{d1} =$ | 1.69350 | $\nu_{d1} =$ | 53.21 |
| $r_2 =$    | 3.067 (Aspheric) | $d_2 =$    | 1.08       |            |         |              |       |
| $r_3 =$    | 4.805            | $d_3 =$    | 0.75       | $n_{d2} =$ | 1.84666 | $\nu_{d2} =$ | 23.78 |
| $r_4 =$    | 7.074            | $d_4 =$    | (Variable) |            |         |              |       |
| $r_5 =$    | $\infty$ (Stop)  | $d_5 =$    | 0.10       |            |         |              |       |
| $r_6 =$    | 3.743 (Aspheric) | $d_6 =$    | 0.80       | $n_{d3} =$ | 1.67790 | $\nu_{d3} =$ | 55.34 |
| $r_7 =$    | -15.671          | $d_7 =$    | 0.89       |            |         |              |       |
| $r_8 =$    | -5.791           | $d_8 =$    | 0.60       | $n_{d4} =$ | 1.76182 | $\nu_{d4} =$ | 26.52 |
| $r_9 =$    | 4.399            | $d_9 =$    | 0.39       |            |         |              |       |
| $r_{10} =$ | 14.092           | $d_{10} =$ | 0.96       | $n_{d5} =$ | 1.78590 | $\nu_{d5} =$ | 44.20 |
| $r_{11} =$ | -4.706           | $d_{11} =$ | (Variable) |            |         |              |       |
| $r_{12} =$ | 5.551 (Aspheric) | $d_{12} =$ | 0.80       | $n_{d6} =$ | 1.78800 | $\nu_{d6} =$ | 47.37 |
| $r_{13} =$ | 6.983            | $d_{13} =$ | (Variable) |            |         |              |       |
| $r_{14} =$ | $\infty$         | $d_{14} =$ | 0.50       | $n_{d7} =$ | 1.51633 | $\nu_{d7} =$ | 64.14 |
| $r_{15} =$ | $\infty$         |            |            |            |         |              |       |

#### Aspherical Coefficients

2nd surface

$$K = -1.200$$

$$A_4 = 3.55109 \times 10^{-3}$$

$$A_6 = 2.56305 \times 10^{-4}$$

$$A_8 = -2.33716 \times 10^{-5}$$

$$A_{10} = 2.07830 \times 10^{-6}$$

6th surface

$$K = -0.728$$

$$A_4 = 7.03429 \times 10^{-4}$$

$$A_6 = -1.42131 \times 10^{-5}$$

$$A_8 = 5.98131 \times 10^{-5}$$

$$A_{10} = -1.12393 \times 10^{-5}$$

12th surface

$$K = -3.851$$



$$A_4 = 1.74180 \times 10^{-3}$$

$$A_6 = 8.82987 \times 10^{-6}$$

$$A_8 = 0$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|                       | WE   | ST   | TE   |
|-----------------------|------|------|------|
| f (mm)                | 4.4  | 6.2  | 8.8  |
| $F_{NO}$              | 2.8  | 3.2  | 4.0  |
| $\omega$ ( $^\circ$ ) | 30.8 | 22.3 | 15.7 |
| $d_4$                 | 4.77 | 1.78 | 0.22 |
| $d_{11}$              | 0.10 | 2.61 | 8.22 |
| $d_{13}$              | 4.13 | 3.49 | 0.56 |

Example 3-2

|            |                   |            |            |            |         |              |       |
|------------|-------------------|------------|------------|------------|---------|--------------|-------|
| $r_1 =$    | -6.951 (Aspheric) | $d_1 =$    | 0.60       | $n_{d1} =$ | 1.67790 | $\nu_{d1} =$ | 55.34 |
| $r_2 =$    | 6.574             | $d_2 =$    | 0.64       | $n_{d2} =$ | 1.84666 | $\nu_{d2} =$ | 23.78 |
| $r_3 =$    | 15.485            | $d_3 =$    | (Variable) |            |         |              |       |
| $r_4 =$    | $\infty$ (Stop)   | $d_4 =$    | 0.10       |            |         |              |       |
| $r_5 =$    | 4.706 (Aspheric)  | $d_5 =$    | 0.69       | $n_{d3} =$ | 1.69350 | $\nu_{d3} =$ | 53.21 |
| $r_6 =$    | -6.848            | $d_6 =$    | 0.17       |            |         |              |       |
| $r_7 =$    | 6.792             | $d_7 =$    | 0.92       | $n_{d4} =$ | 1.80610 | $\nu_{d4} =$ | 40.92 |
| $r_8 =$    | -2.029            | $d_8 =$    | 0.60       | $n_{d5} =$ | 1.68893 | $\nu_{d5} =$ | 31.07 |
| $r_9 =$    | 2.447             | $d_9 =$    | (Variable) |            |         |              |       |
| $r_{10} =$ | -5.488            | $d_{10} =$ | 0.77       | $n_{d6} =$ | 1.68893 | $\nu_{d6} =$ | 31.07 |
| $r_{11} =$ | -3.434 (Aspheric) | $d_{11} =$ | 1.78       |            |         |              |       |
| $r_{12} =$ | $\infty$          | $d_{12} =$ | 0.50       | $n_{d7} =$ | 1.51633 | $\nu_{d7} =$ | 64.14 |
| $r_{13} =$ | $\infty$          |            |            |            |         |              |       |

Aspherical Coefficients

1st surface

$$K = -4.615$$

$$A_4 = -1.30227 \times 10^{-3}$$

$$A_6 = 0$$

$$A_8 = 0$$

$$A_{10} = 0$$

5 th surface

$$K = -3.406$$

$$A_4 = -3.94764 \times 10^{-3}$$

$$A_6 = -7.90797 \times 10^{-4}$$

$$A_8 = 2.03424 \times 10^{-4}$$

$$A_{10} = -1.31727 \times 10^{-4}$$

1 1 th surface

$$K = -0.035$$

$$A_4 = 3.45595 \times 10^{-3}$$

$$A_6 = 0$$

$$A_8 = 0$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|                 | WE   | ST   | TE   |
|-----------------|------|------|------|
| f (mm)          | 4.4  | 6.2  | 8.8  |
| F <sub>NO</sub> | 2.8  | 3.3  | 4.1  |
| $\omega$ (°)    | 32.9 | 21.8 | 15.4 |
| d <sub>3</sub>  | 3.26 | 1.43 | 0.14 |
| d <sub>9</sub>  | 1.88 | 3.18 | 4.99 |

Example 4-1

|                  |                  |                  |            |                   |         |              |       |
|------------------|------------------|------------------|------------|-------------------|---------|--------------|-------|
| r <sub>1</sub> = | -8.544           | d <sub>1</sub> = | 0.60       | n <sub>d1</sub> = | 1.69350 | $\nu_{d1}$ = | 53.21 |
| r <sub>2</sub> = | 5.795 (Aspheric) | d <sub>2</sub> = | 0.44       |                   |         |              |       |
| r <sub>3</sub> = | 7.279            | d <sub>3</sub> = | 0.67       | n <sub>d2</sub> = | 1.84666 | $\nu_{d2}$ = | 23.78 |
| r <sub>4</sub> = | 19.919           | d <sub>4</sub> = | (Variable) |                   |         |              |       |
| r <sub>5</sub> = | $\infty$ (Stop)  | d <sub>5</sub> = | 0.10       |                   |         |              |       |

|            |                    |            |            |            |         |              |       |
|------------|--------------------|------------|------------|------------|---------|--------------|-------|
| $r_6 =$    | 3.655 (Aspheric)   | $d_6 =$    | 1.38       | $n_{d3} =$ | 1.69350 | $\nu_{d3} =$ | 53.21 |
| $r_7 =$    | -14.166            | $d_7 =$    | 0.10       |            |         |              |       |
| $r_8 =$    | 9.263 (Aspheric)   | $d_8 =$    | 0.99       | $n_{d4} =$ | 1.78800 | $\nu_{d4} =$ | 47.37 |
| $r_9 =$    | -2.793             | $d_9 =$    | 0.60       | $n_{d5} =$ | 1.68893 | $\nu_{d5} =$ | 31.07 |
| $r_{10} =$ | 3.038              | $d_{10} =$ | (Variable) |            |         |              |       |
| $r_{11} =$ | 44.064             | $d_{11} =$ | 1.60       | $n_{d6} =$ | 1.78800 | $\nu_{d6} =$ | 47.37 |
| $r_{12} =$ | -4.323             | $d_{12} =$ | 0.16       |            |         |              |       |
| $r_{13} =$ | -3.912             | $d_{13} =$ | 1.60       | $n_{d7} =$ | 1.51633 | $\nu_{d7} =$ | 64.14 |
| $r_{14} =$ | -18.192 (Aspheric) | $d_{14} =$ | 0.10       |            |         |              |       |
| $r_{15} =$ | $\infty$           | $d_{15} =$ | 0.50       | $n_{d8} =$ | 1.51633 | $\nu_{d8} =$ | 64.14 |
| $r_{16} =$ | $\infty$           |            |            |            |         |              |       |

#### Aspherical Coefficients

2nd surface

$$K = -0.856$$

$$A_4 = -5.31098 \times 10^{-4}$$

$$A_6 = 2.90922 \times 10^{-4}$$

$$A_8 = -6.35097 \times 10^{-5}$$

$$A_{10} = 5.38366 \times 10^{-6}$$

6th surface

$$K = 0.057$$

$$A_4 = -2.33967 \times 10^{-4}$$

$$A_6 = 6.09317 \times 10^{-6}$$

$$A_8 = 8.12573 \times 10^{-5}$$

$$A_{10} = -1.66984 \times 10^{-5}$$

8th surface

$$K = -33.940$$

$$A_4 = -1.48982 \times 10^{-3}$$

$$A_6 = -1.35589 \times 10^{-3}$$

$$A_8 = 0$$

$$A_{10} = 0$$

1 4 th surface

$$K = 0.000$$

$$A_4 = 7.17227 \times 10^{-3}$$

$$A_6 = -6.23670 \times 10^{-4}$$

$$A_8 = 0$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|                 | WE   | ST   | TE   |
|-----------------|------|------|------|
| f (mm)          | 4.4  | 6.2  | 8.8  |
| F <sub>NO</sub> | 2.8  | 3.3  | 4.1  |
| $\omega$ (°)    | 33.1 | 22.1 | 15.6 |
| d <sub>4</sub>  | 3.63 | 1.58 | 0.14 |
| d <sub>10</sub> | 2.14 | 3.59 | 5.65 |

Example 4-2

|                   |                   |                   |            |                   |         |              |       |
|-------------------|-------------------|-------------------|------------|-------------------|---------|--------------|-------|
| r <sub>1</sub> =  | -6.328            | d <sub>1</sub> =  | 0.60       | n <sub>d1</sub> = | 1.69350 | $\nu_{d1}$ = | 53.21 |
| r <sub>2</sub> =  | 3.092             | d <sub>2</sub> =  | 1.03       | n <sub>d2</sub> = | 1.81474 | $\nu_{d2}$ = | 37.03 |
| r <sub>3</sub> =  | 11.872            | d <sub>3</sub> =  | (Variable) |                   |         |              |       |
| r <sub>4</sub> =  | 3.024 (Aspheric)  | d <sub>4</sub> =  | 1.08       | n <sub>d3</sub> = | 1.69350 | $\nu_{d3}$ = | 53.21 |
| r <sub>5</sub> =  | 36.382            | d <sub>5</sub> =  | 0.12       |                   |         |              |       |
| r <sub>6</sub> =  | $\infty$ (Stop)   | d <sub>6</sub> =  | 0.10       |                   |         |              |       |
| r <sub>7</sub> =  | 4.427 (Aspheric)  | d <sub>7</sub> =  | 0.99       | n <sub>d4</sub> = | 1.78800 | $\nu_{d4}$ = | 47.37 |
| r <sub>8</sub> =  | -7.290            | d <sub>8</sub> =  | 1.20       | n <sub>d5</sub> = | 1.84666 | $\nu_{d5}$ = | 23.78 |
| r <sub>9</sub> =  | 3.680 (Aspheric)  | d <sub>9</sub> =  | (Variable) |                   |         |              |       |
| r <sub>10</sub> = | -7.523            | d <sub>10</sub> = | 1.20       | n <sub>d6</sub> = | 1.80610 | $\nu_{d6}$ = | 40.92 |
| r <sub>11</sub> = | -2.849            | d <sub>11</sub> = | 0.16       |                   |         |              |       |
| r <sub>12</sub> = | -2.632            | d <sub>12</sub> = | 1.16       | n <sub>d7</sub> = | 1.49700 | $\nu_{d7}$ = | 81.54 |
| r <sub>13</sub> = | -6.396 (Aspheric) | d <sub>13</sub> = | 0.79       |                   |         |              |       |
| r <sub>14</sub> = | $\infty$          | d <sub>14</sub> = | 0.50       | n <sub>d8</sub> = | 1.51633 | $\nu_{d8}$ = | 64.14 |
| r <sub>15</sub> = | $\infty$          | d <sub>15</sub>   |            |                   |         |              |       |

# Aspherical Coefficients

4 th surface

$$K = 0.396$$

$$A_4 = 2.09373 \times 10^{-3}$$

$$A_6 = -1.62524 \times 10^{-4}$$

$$A_8 = 2.20952 \times 10^{-4}$$

$$A_{10} = -2.31731 \times 10^{-5}$$

7 th surface

$$K = -8.236$$

$$A_4 = 1.60630 \times 10^{-3}$$

$$A_6 = -3.38827 \times 10^{-3}$$

$$A_8 = -3.72604 \times 10^{-4}$$

$$A_{10} = 0$$

9 th surface

$$K = 0.344$$

$$A_4 = 8.07095 \times 10^{-3}$$

$$A_6 = -7.93864 \times 10^{-4}$$

$$A_8 = 0$$

$$A_{10} = 0$$

1 3 th surface

$$K = 0.000$$

$$A_4 = 3.88351 \times 10^{-3}$$

$$A_6 = -5.71375 \times 10^{-4}$$

$$A_8 = 0$$

$$A_{10} = 0$$

## Zooming Data ( $\infty$ )

|                 | WE   | ST   | TE   |
|-----------------|------|------|------|
| f (mm)          | 4.4  | 6.2  | 8.8  |
| F <sub>NO</sub> | 2.8  | 3.4  | 4.3  |
| $\omega$ (°)    | 33.5 | 22.2 | 15.8 |

|       |      |      |      |
|-------|------|------|------|
| $d_3$ | 2.76 | 1.21 | 0.10 |
| $d_9$ | 0.65 | 1.78 | 3.33 |

#### Example 5 - 1

|            |                    |            |            |            |         |              |       |
|------------|--------------------|------------|------------|------------|---------|--------------|-------|
| $r_1 =$    | -15.253 (Aspheric) | $d_1 =$    | 0.60       | $n_{d1} =$ | 1.69350 | $\nu_{d1} =$ | 53.21 |
| $r_2 =$    | 4.141              | $d_2 =$    | 0.96       | $n_{d2} =$ | 1.68893 | $\nu_{d2} =$ | 31.07 |
| $r_3 =$    | 12.214 (Aspheric)  | $d_3 =$    | (Variable) |            |         |              |       |
| $r_4 =$    | $\infty$ (Stop)    | $d_4 =$    | 0.10       |            |         |              |       |
| $r_5 =$    | 9.919 (Aspheric)   | $d_5 =$    | 0.68       | $n_{d3} =$ | 1.49700 | $\nu_{d3} =$ | 81.54 |
| $r_6 =$    | -11.002            | $d_6 =$    | 0.10       |            |         |              |       |
| $r_7 =$    | 3.141 (Aspheric)   | $d_7 =$    | 1.33       | $n_{d4} =$ | 1.74320 | $\nu_{d4} =$ | 49.34 |
| $r_8 =$    | -6.830             | $d_8 =$    | 0.62       | $n_{d5} =$ | 1.68893 | $\nu_{d5} =$ | 31.07 |
| $r_9 =$    | 3.671 (Aspheric)   | $d_9 =$    | (Variable) |            |         |              |       |
| $r_{10} =$ | 11.080             | $d_{10} =$ | 1.06       | $n_{d6} =$ | 1.68893 | $\nu_{d6} =$ | 31.07 |
| $r_{11} =$ | 3.943 (Aspheric)   | $d_{11} =$ | (Variable) |            |         |              |       |
| $r_{12} =$ | -13.947            | $d_{12} =$ | 1.11       | $n_{d7} =$ | 1.68893 | $\nu_{d7} =$ | 31.07 |
| $r_{13} =$ | -4.584 (Aspheric)  | $d_{13} =$ | 1.69       |            |         |              |       |
| $r_{14} =$ | $\infty$           | $d_{14} =$ | 0.50       | $n_{d8} =$ | 1.51633 | $\nu_{d8} =$ | 64.14 |
| $r_{15} =$ | $\infty$           |            |            |            |         |              |       |

#### Aspherical Coefficients

1st surface

$$K = -19.399$$

$$A_4 = -9.52491 \times 10^{-4}$$

$$A_6 = 4.99000 \times 10^{-5}$$

$$A_8 = 1.01862 \times 10^{-5}$$

$$A_{10} = 0$$

3rd surface

$$K = -14.812$$

$$A_4 = -8.97149 \times 10^{-4}$$

$$A_6 = 4.01691 \times 10^{-6}$$

$$A_8 = 1.68687 \times 10^{-5}$$

$$A_{10} = 0$$

5 th surface

$$K = 19.348$$

$$A_4 = -4.82828 \times 10^{-3}$$

$$A_6 = 8.06209 \times 10^{-4}$$

$$A_8 = -1.99532 \times 10^{-4}$$

$$A_{10} = 0$$

7 th surface

$$K = -1.011$$

$$A_4 = 7.47480 \times 10^{-3}$$

$$A_6 = -2.60867 \times 10^{-4}$$

$$A_8 = 8.69323 \times 10^{-5}$$

$$A_{10} = 0$$

9 th surface

$$K = -9.730$$

$$A_4 = 3.91180 \times 10^{-2}$$

$$A_6 = -4.30584 \times 10^{-3}$$

$$A_8 = 1.54137 \times 10^{-3}$$

$$A_{10} = 0$$

11 th surface

$$K = -5.280$$

$$A_4 = 1.20789 \times 10^{-2}$$

$$A_6 = -8.05017 \times 10^{-4}$$

$$A_8 = 1.88007 \times 10^{-6}$$

$$A_{10} = 0$$

13 th surface

$$K = -1.512$$

$$A_4 = 1.20543 \times 10^{-4}$$

$$A_6 = -1.73187 \times 10^{-4}$$

$$A_8 = 5.42052 \times 10^{-6}$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|              | WE   | ST   | TE   |
|--------------|------|------|------|
| f (mm)       | 4.7  | 7.6  | 13.0 |
| $F_{NO}$     | 2.8  | 3.8  | 5.1  |
| $\omega$ (°) | 30.3 | 18.1 | 10.7 |
| $d_3$        | 5.47 | 2.88 | 0.18 |
| $d_9$        | 0.74 | 0.35 | 1.39 |
| $d_{11}$     | 0.74 | 3.72 | 5.38 |

Example 5 — 2

|            |                   |            |            |            |         |              |       |
|------------|-------------------|------------|------------|------------|---------|--------------|-------|
| $r_1 =$    | -8.395 (Aspheric) | $d_1 =$    | 0.60       | $n_{d1} =$ | 1.67790 | $\nu_{d1} =$ | 55.34 |
| $r_2 =$    | 4.439             | $d_2 =$    | 0.98       | $n_{d2} =$ | 1.68893 | $\nu_{d2} =$ | 31.07 |
| $r_3 =$    | 21.458 (Aspheric) | $d_3 =$    | (Variable) |            |         |              |       |
| $r_4 =$    | $\infty$ (Stop)   | $d_4 =$    | 0.08       |            |         |              |       |
| $r_5 =$    | 13.194 (Aspheric) | $d_5 =$    | 0.65       | $n_{d3} =$ | 1.49700 | $\nu_{d3} =$ | 81.54 |
| $r_6 =$    | -10.912           | $d_6 =$    | 0.19       |            |         |              |       |
| $r_7 =$    | 2.999 (Aspheric)  | $d_7 =$    | 1.34       | $n_{d4} =$ | 1.74320 | $\nu_{d4} =$ | 49.34 |
| $r_8 =$    | -5.935            | $d_8 =$    | 0.60       | $n_{d5} =$ | 1.68893 | $\nu_{d5} =$ | 31.07 |
| $r_9 =$    | 3.541 (Aspheric)  | $d_9 =$    | (Variable) |            |         |              |       |
| $r_{10} =$ | -54.527           | $d_{10} =$ | 0.60       | $n_{d6} =$ | 1.68893 | $\nu_{d6} =$ | 31.07 |
| $r_{11} =$ | 6.260 (Aspheric)  | $d_{11} =$ | (Variable) |            |         |              |       |
| $r_{12} =$ | 30.988            | $d_{12} =$ | 1.48       | $n_{d7} =$ | 1.68893 | $\nu_{d7} =$ | 31.07 |
| $r_{13} =$ | -5.446 (Aspheric) | $d_{13} =$ | 1.00       |            |         |              |       |
| $r_{14} =$ | $\infty$          | $d_{14} =$ | 0.50       | $n_{d8} =$ | 1.51633 | $\nu_{d8} =$ | 64.14 |
| $r_{15} =$ | $\infty$          |            |            |            |         |              |       |

Aspherical Coefficients

1st surface

$$K = 0.576$$



$$A_4 = -6.63222 \times 10^{-4}$$

$$A_6 = 5.19142 \times 10^{-5}$$

$$A_8 = 3.41858 \times 10^{-6}$$

$$A_{10} = 0$$

3rd surface

$$K = -31.443$$

$$A_4 = -4.24448 \times 10^{-4}$$

$$A_6 = -2.32455 \times 10^{-7}$$

$$A_8 = 1.82275 \times 10^{-5}$$

$$A_{10} = 0$$

5th surface

$$K = 32.850$$

$$A_4 = -2.19377 \times 10^{-3}$$

$$A_6 = -7.72833 \times 10^{-5}$$

$$A_8 = 7.53132 \times 10^{-6}$$

$$A_{10} = 0$$

7th surface

$$K = -1.055$$

$$A_4 = 7.33888 \times 10^{-3}$$

$$A_6 = 4.41996 \times 10^{-4}$$

$$A_8 = -1.81717 \times 10^{-5}$$

$$A_{10} = 0$$

9th surface

$$K = -10.179$$

$$A_4 = 4.50999 \times 10^{-2}$$

$$A_6 = -4.61578 \times 10^{-3}$$

$$A_8 = 1.84744 \times 10^{-3}$$

$$A_{10} = 0$$

11th surface

$$K = -24.461$$

$$A_4 = 1.24411 \times 10^{-2}$$

$$A_6 = -2.06313 \times 10^{-3}$$

$$A_8 = 1.94143 \times 10^{-4}$$

$$A_{10} = 0$$

13th surface

$$K = -11.947$$

$$A_4 = -4.12632 \times 10^{-3}$$

$$A_6 = 2.43311 \times 10^{-4}$$

$$A_8 = -7.32948 \times 10^{-6}$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|                       | WE   | ST   | TE   |
|-----------------------|------|------|------|
| f (mm)                | 4.7  | 7.6  | 13.0 |
| $F_{NO}$              | 2.8  | 3.8  | 5.0  |
| $\omega$ ( $^\circ$ ) | 31.6 | 18.2 | 10.6 |
| $d_3$                 | 6.04 | 3.32 | 0.55 |
| $d_9$                 | 1.34 | 1.32 | 2.66 |
| $d_{11}$              | 1.76 | 4.49 | 5.93 |

Example 6-1

|                          |                              |                    |                    |
|--------------------------|------------------------------|--------------------|--------------------|
| $r_1 = -235.855$         | $d_1 = 0.60$                 | $n_{d1} = 1.69350$ | $\nu_{d1} = 53.21$ |
| $r_2 = 3.549$ (Aspheric) | $d_2 = 1.59$                 |                    |                    |
| $r_3 = 6.625$            | $d_3 = 0.91$                 | $n_{d2} = 1.84666$ | $\nu_{d2} = 23.78$ |
| $r_4 = 12.436$           | $d_4 = \text{(Variable)}$    |                    |                    |
| $r_5 = \infty$ (Stop)    | $d_5 = 0.10$                 |                    |                    |
| $r_6 = 3.797$ (Aspheric) | $d_6 = 1.06$                 | $n_{d3} = 1.69350$ | $\nu_{d3} = 53.21$ |
| $r_7 = -17.794$          | $d_7 = 0.10$                 |                    |                    |
| $r_8 = 7.931$ (Aspheric) | $d_8 = 0.78$                 | $n_{d4} = 1.78800$ | $\nu_{d4} = 47.37$ |
| $r_9 = -4.713$           | $d_9 = 0.60$                 | $n_{d5} = 1.68893$ | $\nu_{d5} = 31.07$ |
| $r_{10} = 2.574$         | $d_{10} = \text{(Variable)}$ |                    |                    |

|            |                   |            |            |            |         |              |       |
|------------|-------------------|------------|------------|------------|---------|--------------|-------|
| $r_{11} =$ | 4.259             | $d_{11} =$ | 0.66       | $n_{d6} =$ | 1.49700 | $\nu_{d6} =$ | 81.54 |
| $r_{12} =$ | 6.233 (Aspheric)  | $d_{12} =$ | (Variable) |            |         |              |       |
| $r_{13} =$ | $\infty$          | $d_{13} =$ | 0.79       | $n_{d7} =$ | 1.74320 | $\nu_{d7} =$ | 49.34 |
| $r_{14} =$ | -8.029 (Aspheric) | $d_{14} =$ | (Variable) |            |         |              |       |
| $r_{15} =$ | $\infty$          | $d_{15} =$ | 0.50       | $n_{d8} =$ | 1.51633 | $\nu_{d8} =$ | 64.14 |
| $r_{16} =$ | $\infty$          |            |            |            |         |              |       |

#### Aspherical Coefficients

2nd surface

$$K = -0.565$$

$$A_4 = -1.29926 \times 10^{-4}$$

$$A_6 = 1.05590 \times 10^{-4}$$

$$A_8 = -7.93901 \times 10^{-6}$$

$$A_{10} = 2.72375 \times 10^{-7}$$

6th surface

$$K = -0.137$$

$$A_4 = -1.31726 \times 10^{-3}$$

$$A_6 = -1.41891 \times 10^{-4}$$

$$A_8 = 6.88204 \times 10^{-5}$$

$$A_{10} = -1.74013 \times 10^{-5}$$

8th surface

$$K = -1.367$$

$$A_4 = -1.60327 \times 10^{-3}$$

$$A_6 = -1.35433 \times 10^{-4}$$

$$A_8 = 0$$

$$A_{10} = 0$$

12th surface

$$K = 0.000$$

$$A_4 = 1.72530 \times 10^{-3}$$

$$A_6 = 2.23148 \times 10^{-5}$$

$$A_8 = 0$$

$$A_{10} = 0$$

1 4 th surface

$$K = -14.842$$

$$A_4 = -1.74997 \times 10^{-4}$$

$$A_6 = 2.64295 \times 10^{-6}$$

$$A_8 = 0$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|                 | WE   | ST   | TE   |
|-----------------|------|------|------|
| f (mm)          | 3.0  | 5.2  | 9.0  |
| F <sub>NO</sub> | 2.8  | 3.7  | 5.3  |
| $\omega$ (°)    | 45.5 | 25.7 | 15.3 |
| d <sub>4</sub>  | 7.91 | 3.24 | 0.91 |
| d <sub>10</sub> | 0.24 | 2.88 | 6.07 |
| d <sub>12</sub> | 2.12 | 2.25 | 4.11 |
| d <sub>14</sub> | 1.01 | 1.07 | 0.18 |

Example 6 – 2

|                                     |                              |                           |                    |
|-------------------------------------|------------------------------|---------------------------|--------------------|
| r <sub>1</sub> = $\infty$           | d <sub>1</sub> = 0.60        | n <sub>d1</sub> = 1.51633 | $\nu_{d1}$ = 64.14 |
| r <sub>2</sub> = 2.950 (Aspheric)   | d <sub>2</sub> = 2.52        |                           |                    |
| r <sub>3</sub> = 5.433              | d <sub>3</sub> = 0.80        | n <sub>d2</sub> = 1.84666 | $\nu_{d2}$ = 23.78 |
| r <sub>4</sub> = 6.933              | d <sub>4</sub> = (Variable)  |                           |                    |
| r <sub>5</sub> = $\infty$ (Stop)    | d <sub>5</sub> = 0.10        |                           |                    |
| r <sub>6</sub> = 3.215 (Aspheric)   | d <sub>6</sub> = 0.81        | n <sub>d3</sub> = 1.58313 | $\nu_{d3}$ = 59.38 |
| r <sub>7</sub> = -88.640            | d <sub>7</sub> = 0.10        |                           |                    |
| r <sub>8</sub> = 5.867 (Aspheric)   | d <sub>8</sub> = 0.74        | n <sub>d4</sub> = 1.78800 | $\nu_{d4}$ = 47.37 |
| r <sub>9</sub> = -8.024             | d <sub>9</sub> = 0.60        | n <sub>d5</sub> = 1.68893 | $\nu_{d5}$ = 31.07 |
| r <sub>10</sub> = 2.566             | d <sub>10</sub> = (Variable) |                           |                    |
| r <sub>11</sub> = 7.991             | d <sub>11</sub> = 0.60       | n <sub>d6</sub> = 1.49700 | $\nu_{d6}$ = 81.54 |
| r <sub>12</sub> = 27.210 (Aspheric) | d <sub>12</sub> = (Variable) |                           |                    |

|            |                   |            |            |            |         |              |       |
|------------|-------------------|------------|------------|------------|---------|--------------|-------|
| $r_{13} =$ | -29.417           | $d_{13} =$ | 0.99       | $n_{d7} =$ | 1.49700 | $\nu_{d7} =$ | 81.54 |
| $r_{14} =$ | -5.069 (Aspheric) | $d_{14} =$ | (Variable) |            |         |              |       |
| $r_{15} =$ | $\infty$          | $d_{15} =$ | 0.50       | $n_{d8} =$ | 1.51633 | $\nu_{d8} =$ | 64.14 |
| $r_{16} =$ | $\infty$          |            |            |            |         |              |       |

#### Aspherical Coefficients

2nd surface

$K = -0.893$

$A_4 = 1.45261 \times 10^{-3}$

$A_6 = 1.41038 \times 10^{-4}$

$A_8 = -7.01509 \times 10^{-6}$

$A_{10} = 4.11221 \times 10^{-7}$

6th surface

$K = 0.128$

$A_4 = 1.53677 \times 10^{-5}$

$A_6 = -8.68099 \times 10^{-5}$

$A_8 = 2.50336 \times 10^{-4}$

$A_{10} = -3.99233 \times 10^{-5}$

8th surface

$K = -2.777$

$A_4 = -2.28635 \times 10^{-3}$

$A_6 = -5.33394 \times 10^{-4}$

$A_8 = -1.51884 \times 10^{-4}$

$A_{10} = 0$

12th surface

$K = 0.000$

$A_4 = 2.30056 \times 10^{-3}$

$A_6 = -1.45665 \times 10^{-4}$

$A_8 = 2.87717 \times 10^{-5}$

$A_{10} = 0$

14th surface

$$K = -2.859$$

$$A_4 = -1.27245 \times 10^{-4}$$

$$A_6 = -4.60322 \times 10^{-5}$$

$$A_8 = -3.26441 \times 10^{-6}$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|              | WE   | ST   | TE   |
|--------------|------|------|------|
| f (mm)       | 3.0  | 5.2  | 9.0  |
| $F_{NO}$     | 2.8  | 3.3  | 5.4  |
| $\omega$ (°) | 43.9 | 25.8 | 15.8 |
| $d_4$        | 7.57 | 1.59 | 0.74 |
| $d_{10}$     | 0.37 | 0.66 | 3.80 |
| $d_{12}$     | 1.44 | 1.79 | 6.68 |
| $d_{14}$     | 1.96 | 3.15 | 0.10 |

Example 6 — 3

|                               |                              |                    |                    |
|-------------------------------|------------------------------|--------------------|--------------------|
| $r_1 = -39.641$               | $d_1 = 0.60$                 | $n_{d1} = 1.69350$ | $\nu_{d1} = 53.21$ |
| $r_2 = 3.758$ (Aspheric)      | $d_2 = 1.62$                 |                    |                    |
| $r_3 = 7.085$                 | $d_3 = 0.83$                 | $n_{d2} = 1.84666$ | $\nu_{d2} = 23.78$ |
| $r_4 = 13.743$                | $d_4 = (\text{Variable})$    |                    |                    |
| $r_5 = \infty$ (Stop)         | $d_5 = 0.10$                 |                    |                    |
| $r_6 = 3.644$ (Aspheric)      | $d_6 = 1.36$                 | $n_{d3} = 1.69350$ | $\nu_{d3} = 53.21$ |
| $r_7 = -23.518$               | $d_7 = 0.10$                 |                    |                    |
| $r_8 = 8.588$ (Aspheric)      | $d_8 = 0.82$                 | $n_{d4} = 1.78800$ | $\nu_{d4} = 47.37$ |
| $r_9 = -3.659$                | $d_9 = 0.60$                 | $n_{d5} = 1.68893$ | $\nu_{d5} = 31.07$ |
| $r_{10} = 2.800$              | $d_{10} = (\text{Variable})$ |                    |                    |
| $r_{11} = 4.441$              | $d_{11} = 1.29$              | $n_{d6} = 1.49700$ | $\nu_{d6} = 81.54$ |
| $r_{12} = 4.321$ (Aspheric)   | $d_{12} = (\text{Variable})$ |                    |                    |
| $r_{13} = 5.613$              | $d_{13} = 1.20$              | $n_{d7} = 1.69350$ | $\nu_{d7} = 53.21$ |
| $r_{14} = 556.044$ (Aspheric) | $d_{14} = 0.22$              |                    |                    |

$$r_{15} = \infty \quad d_{15} = 0.50 \quad n_{d8} = 1.51633 \quad \nu_{d8} = 64.14$$

$$r_{16} = \infty$$

#### Aspherical Coefficients

2nd surface

$$K = -0.730$$

$$A_4 = 1.40877 \times 10^{-6}$$

$$A_6 = 1.25212 \times 10^{-4}$$

$$A_8 = -9.63026 \times 10^{-6}$$

$$A_{10} = 3.57391 \times 10^{-7}$$

6th surface

$$K = 0.181$$

$$A_4 = -3.50134 \times 10^{-4}$$

$$A_6 = -9.65305 \times 10^{-5}$$

$$A_8 = 1.52691 \times 10^{-4}$$

$$A_{10} = -3.81912 \times 10^{-5}$$

8th surface

$$K = -19.376$$

$$A_4 = -1.33804 \times 10^{-3}$$

$$A_6 = -1.00926 \times 10^{-3}$$

$$A_8 = 0$$

$$A_{10} = 0$$

12th surface

$$K = 0.000$$

$$A_4 = -1.98092 \times 10^{-4}$$

$$A_6 = 1.58372 \times 10^{-4}$$

$$A_8 = 0$$

$$A_{10} = 0$$

14th surface

$$K = 0.000$$

$$A_4 = 4.78191 \times 10^{-3}$$

$$A_6 = -3.69614 \times 10^{-4}$$

$$A_8 = 0$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|                 | WE   | ST   | TE   |
|-----------------|------|------|------|
| f (mm)          | 3.0  | 5.2  | 9.0  |
| F <sub>NO</sub> | 2.8  | 3.7  | 5.2  |
| $\omega$ (°)    | 46.4 | 25.8 | 14.8 |
| d <sub>4</sub>  | 7.08 | 2.79 | 0.22 |
| d <sub>10</sub> | 0.23 | 4.07 | 6.51 |
| d <sub>12</sub> | 1.91 | 0.90 | 2.49 |

Example 7-1

|                                     |                              |                           |                    |
|-------------------------------------|------------------------------|---------------------------|--------------------|
| r <sub>1</sub> = 16.444 (Aspheric)  | d <sub>1</sub> = 1.11        | n <sub>d1</sub> = 1.49700 | $\nu_{d1}$ = 81.54 |
| r <sub>2</sub> = -10.268            | d <sub>2</sub> = (Variable)  |                           |                    |
| r <sub>3</sub> = -6.588 (Aspheric)  | d <sub>3</sub> = 0.60        | n <sub>d2</sub> = 1.81600 | $\nu_{d2}$ = 46.62 |
| r <sub>4</sub> = 4.660              | d <sub>4</sub> = 0.81        | n <sub>d3</sub> = 1.84666 | $\nu_{d3}$ = 23.78 |
| r <sub>5</sub> = 10.739             | d <sub>5</sub> = (Variable)  |                           |                    |
| r <sub>6</sub> = $\infty$ (Stop)    | d <sub>6</sub> = (Variable)  |                           |                    |
| r <sub>7</sub> = 2.889 (Aspheric)   | d <sub>7</sub> = 1.73        | n <sub>d4</sub> = 1.72916 | $\nu_{d4}$ = 54.68 |
| r <sub>8</sub> = -6.939             | d <sub>8</sub> = 0.10        |                           |                    |
| r <sub>9</sub> = -296.907           | d <sub>9</sub> = 1.00        | n <sub>d5</sub> = 1.84666 | $\nu_{d5}$ = 23.78 |
| r <sub>10</sub> = 2.764 (Aspheric)  | d <sub>10</sub> = (Variable) |                           |                    |
| r <sub>11</sub> = 10.958 (Aspheric) | d <sub>11</sub> = 0.69       | n <sub>d6</sub> = 1.84666 | $\nu_{d6}$ = 23.78 |
| r <sub>12</sub> = -38.512           | d <sub>12</sub> = (Variable) |                           |                    |
| r <sub>13</sub> = $\infty$          | d <sub>13</sub> = 0.50       | n <sub>d7</sub> = 1.51633 | $\nu_{d7}$ = 64.14 |
| r <sub>14</sub> = $\infty$          |                              |                           |                    |

Aspherical Coefficients

1st surface

$$K = 0.000$$



$$A_4 = -3.90951 \times 10^{-4}$$

$$A_6 = -1.51396 \times 10^{-5}$$

$$A_8 = -1.67063 \times 10^{-7}$$

$$A_{10} = 0$$

3rd surface

$$K = -8.941$$

$$A_4 = -2.25798 \times 10^{-3}$$

$$A_6 = 1.84228 \times 10^{-4}$$

$$A_8 = -6.78364 \times 10^{-6}$$

$$A_{10} = 0$$

7th surface

$$K = 0.149$$

$$A_4 = -5.76087 \times 10^{-3}$$

$$A_6 = -3.03438 \times 10^{-4}$$

$$A_8 = -1.86281 \times 10^{-4}$$

$$A_{10} = 1.78319 \times 10^{-5}$$

10th surface

$$K = -0.789$$

$$A_4 = 1.46423 \times 10^{-2}$$

$$A_6 = 1.70602 \times 10^{-3}$$

$$A_8 = -1.02432 \times 10^{-4}$$

$$A_{10} = 0$$

11th surface

$$K = -1.302$$

$$A_4 = 1.42750 \times 10^{-3}$$

$$A_6 = 3.40229 \times 10^{-5}$$

$$A_8 = -3.10139 \times 10^{-6}$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

WE

ST

TE

|                 |      |      |      |
|-----------------|------|------|------|
| f (mm)          | 4.4  | 7.6  | 13.2 |
| F <sub>NO</sub> | 2.8  | 3.3  | 4.3  |
| $\omega$ (°)    | 33.4 | 17.9 | 10.5 |
| d <sub>2</sub>  | 0.21 | 1.63 | 3.00 |
| d <sub>5</sub>  | 4.45 | 1.68 | 0.16 |
| d <sub>6</sub>  | 1.86 | 1.55 | 0.10 |
| d <sub>10</sub> | 0.36 | 1.53 | 2.25 |
| d <sub>12</sub> | 3.24 | 3.73 | 4.61 |

#### Example 7 – 2

|                   |                   |                   |            |                   |         |              |       |
|-------------------|-------------------|-------------------|------------|-------------------|---------|--------------|-------|
| r <sub>1</sub> =  | 12.875 (Aspheric) | d <sub>1</sub> =  | 1.22       | n <sub>d1</sub> = | 1.49700 | $\nu_{d1}$ = | 81.54 |
| r <sub>2</sub> =  | -11.898           | d <sub>2</sub> =  | (Variable) |                   |         |              |       |
| r <sub>3</sub> =  | -6.694 (Aspheric) | d <sub>3</sub> =  | 0.60       | n <sub>d2</sub> = | 1.81600 | $\nu_{d2}$ = | 46.62 |
| r <sub>4</sub> =  | 4.386             | d <sub>4</sub> =  | 0.38       |                   |         |              |       |
| r <sub>5</sub> =  | 5.629             | d <sub>5</sub> =  | 0.78       | n <sub>d3</sub> = | 1.84666 | $\nu_{d3}$ = | 23.78 |
| r <sub>6</sub> =  | 15.581            | d <sub>6</sub> =  | (Variable) |                   |         |              |       |
| r <sub>7</sub> =  | $\infty$ (Stop)   | d <sub>7</sub> =  | (Variable) |                   |         |              |       |
| r <sub>8</sub> =  | 2.890 (Aspheric)  | d <sub>8</sub> =  | 2.00       | n <sub>d4</sub> = | 1.72916 | $\nu_{d4}$ = | 54.68 |
| r <sub>9</sub> =  | -7.475            | d <sub>9</sub> =  | 0.10       |                   |         |              |       |
| r <sub>10</sub> = | -40.151           | d <sub>10</sub> = | 0.60       | n <sub>d5</sub> = | 1.84666 | $\nu_{d5}$ = | 23.78 |
| r <sub>11</sub> = | 3.043 (Aspheric)  | d <sub>11</sub> = | (Variable) |                   |         |              |       |
| r <sub>12</sub> = | 8.251 (Aspheric)  | d <sub>12</sub> = | 0.65       | n <sub>d6</sub> = | 1.84666 | $\nu_{d6}$ = | 23.78 |
| r <sub>13</sub> = | 110.712           | d <sub>13</sub> = | (Variable) |                   |         |              |       |
| r <sub>14</sub> = | $\infty$          | d <sub>14</sub> = | 0.50       | n <sub>d7</sub> = | 1.51633 | $\nu_{d7}$ = | 64.14 |
| r <sub>15</sub> = | $\infty$          |                   |            |                   |         |              |       |

#### Aspherical Coefficients

1st surface

K = 0.000

A<sub>4</sub> = -2.87331  $\times 10^{-4}$

A<sub>6</sub> = -1.36425  $\times 10^{-5}$

$$A_8 = -2.10759 \times 10^{-7}$$

$$A_{10} = 0$$

3rd surface

$$K = -6.859$$

$$A_4 = -6.46103 \times 10^{-4}$$

$$A_6 = 6.43816 \times 10^{-5}$$

$$A_8 = -2.35771 \times 10^{-6}$$

$$A_{10} = 0$$

8th surface

$$K = 0.202$$

$$A_4 = -4.23004 \times 10^{-3}$$

$$A_6 = -5.62239 \times 10^{-4}$$

$$A_8 = 1.16888 \times 10^{-5}$$

$$A_{10} = -2.46485 \times 10^{-5}$$

11th surface

$$K = -0.930$$

$$A_4 = 1.38536 \times 10^{-2}$$

$$A_6 = 1.65230 \times 10^{-3}$$

$$A_8 = 1.48060 \times 10^{-4}$$

$$A_{10} = 0$$

12th surface

$$K = -4.825$$

$$A_4 = 1.27515 \times 10^{-3}$$

$$A_6 = 1.23670 \times 10^{-4}$$

$$A_8 = -2.14636 \times 10^{-5}$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|                 | WE  | ST  | TE   |
|-----------------|-----|-----|------|
| f (mm)          | 4.4 | 7.6 | 13.2 |
| F <sub>NO</sub> | 2.8 | 3.5 | 4.1  |

|                     |      |      |      |
|---------------------|------|------|------|
| $\omega (^{\circ})$ | 33.0 | 17.9 | 10.5 |
| $d_2$               | 0.25 | 1.67 | 2.81 |
| $d_6$               | 5.38 | 3.17 | 0.15 |
| $d_7$               | 1.16 | 0.15 | 0.10 |
| $d_{11}$            | 0.30 | 1.42 | 2.02 |
| $d_{13}$            | 3.87 | 4.53 | 5.87 |

#### Example 7 - 3

|            |                   |            |            |            |         |              |       |
|------------|-------------------|------------|------------|------------|---------|--------------|-------|
| $r_1 =$    | 11.725 (Aspheric) | $d_1 =$    | 1.09       | $n_{d1} =$ | 1.49700 | $\nu_{d1} =$ | 81.54 |
| $r_2 =$    | -16.531           | $d_2 =$    | (Variable) |            |         |              |       |
| $r_3 =$    | -8.820 (Aspheric) | $d_3 =$    | 0.60       | $n_{d2} =$ | 1.81600 | $\nu_{d2} =$ | 46.62 |
| $r_4 =$    | 4.699             | $d_4 =$    | 0.42       |            |         |              |       |
| $r_5 =$    | 5.723             | $d_5 =$    | 0.74       | $n_{d3} =$ | 1.84666 | $\nu_{d3} =$ | 23.78 |
| $r_6 =$    | 13.620            | $d_6 =$    | (Variable) |            |         |              |       |
| $r_7 =$    | $\infty$ (Stop)   | $d_7 =$    | (Variable) |            |         |              |       |
| $r_8 =$    | 3.020 (Aspheric)  | $d_8 =$    | 1.71       | $n_{d4} =$ | 1.72916 | $\nu_{d4} =$ | 54.68 |
| $r_9 =$    | -7.650            | $d_9 =$    | 0.10       |            |         |              |       |
| $r_{10} =$ | -55.896           | $d_{10} =$ | 0.89       | $n_{d5} =$ | 1.84666 | $\nu_{d5} =$ | 23.78 |
| $r_{11} =$ | 3.002 (Aspheric)  | $d_{11} =$ | (Variable) |            |         |              |       |
| $r_{12} =$ | 5.067 (Aspheric)  | $d_{12} =$ | 0.80       | $n_{d6} =$ | 1.84666 | $\nu_{d6} =$ | 23.78 |
| $r_{13} =$ | 12.083            | $d_{13} =$ | (Variable) |            |         |              |       |
| $r_{14} =$ | $\infty$          | $d_{14} =$ | 0.50       | $n_{d7} =$ | 1.51633 | $\nu_{d7} =$ | 64.14 |
| $r_{15} =$ | $\infty$          |            |            |            |         |              |       |

#### Aspherical Coefficients

1st surface

$$K = 0.000$$

$$A_4 = -1.66609 \times 10^{-4}$$

$$A_6 = -2.74210 \times 10^{-6}$$

$$A_8 = -1.85730 \times 10^{-7}$$

$$A_{10} = 0$$

3rd surface

$$K = -12.939$$

$$A_4 = -1.39316 \times 10^{-3}$$

$$A_6 = 9.75592 \times 10^{-5}$$

$$A_8 = -2.56373 \times 10^{-6}$$

$$A_{10} = 0$$

8th surface

$$K = -0.005$$

$$A_4 = -3.06313 \times 10^{-3}$$

$$A_6 = -2.32293 \times 10^{-4}$$

$$A_8 = -7.53412 \times 10^{-5}$$

$$A_{10} = 3.30742 \times 10^{-6}$$

11th surface

$$K = -1.189$$

$$A_4 = 1.28018 \times 10^{-2}$$

$$A_6 = 1.75616 \times 10^{-3}$$

$$A_8 = -7.21525 \times 10^{-5}$$

$$A_{10} = 0$$

12th surface

$$K = -4.764$$

$$A_4 = 3.80909 \times 10^{-3}$$

$$A_6 = -1.52897 \times 10^{-4}$$

$$A_8 = 5.78542 \times 10^{-6}$$

$$A_{10} = 0$$

Zooming Data ( $\infty$ )

|                       | WE   | ST   | TE   |
|-----------------------|------|------|------|
| f (mm)                | 4.4  | 7.6  | 13.2 |
| F <sub>NO</sub>       | 2.8  | 3.4  | 3.9  |
| $\omega$ ( $^\circ$ ) | 34.3 | 17.9 | 10.4 |
| d <sub>2</sub>        | 0.24 | 2.31 | 4.55 |

|          |      |      |      |
|----------|------|------|------|
| $d_6$    | 4.46 | 2.39 | 0.15 |
| $d_7$    | 2.61 | 1.19 | 0.10 |
| $d_{11}$ | 0.25 | 1.54 | 3.28 |
| $d_{13}$ | 3.31 | 3.45 | 2.80 |

Set out below are the values of conditions (2A) and (3A) in Examples 1-1 and 1-2.

|                          | <u>Example 1-1</u> | <u>Example 1-2</u> |
|--------------------------|--------------------|--------------------|
| Condition (2A)           | 2.85               | 5.36               |
| 5 Condition (3A)         |                    |                    |
| (Object-Side Lens)       | 1.16               | 0.68               |
| <u>(Image-Side Lens)</u> | <u>1.03</u>        | <u>-</u>           |

Set out below are the values of conditions (2B) and (3B) in Examples 2-1 and 2-2.

|                             | <u>Example 2-1</u> | <u>Example 2-2</u> |
|-----------------------------|--------------------|--------------------|
| Condition (2B)              | 2.85               | 5.36               |
| Condition (3B)              |                    |                    |
| (Object-Side Lens)          | 1.16               | 0.68               |
| 15 <u>(Image-Side Lens)</u> | <u>1.03</u>        | <u>-</u>           |

Set out below are the values of conditions (2C), (3C) and (4C) in Examples 3-1 and 3-2.

|                       | <u>Example 3-1</u> | <u>Example 3-2</u> |
|-----------------------|--------------------|--------------------|
| 20 Condition (2C)     | 6.08               | 3.95               |
| Condition (3C)        |                    |                    |
| (Object-Side Lens)    | 1.43               | 1.13               |
| (Image-Side Lens)     | 1.89               | 0.78               |
| <u>Condition (4C)</u> | <u>12.05</u>       | <u>4.34</u>        |

25

Set out below are the values of conditions (2C), (3C) and (4C) in Examples 3-1 and 3-2.

|                       | <u>Example 3-1</u> | <u>Example 3-2</u> |
|-----------------------|--------------------|--------------------|
| Condition (2C)        | 6.08               | 3.95               |
| Condition (3C)        |                    |                    |
| (Object-Side Lens)    | 1.43               | 1.13               |
| (Image-Side Lens)     | 1.89               | 0.78               |
| <u>Condition (4C)</u> | <u>12.05</u>       | <u>4.34</u>        |

Set out below are the values of conditions (2D), (3D) and (4D) in Examples 4-1 and 4-2.

|                       | <u>Example 4-1</u> | <u>Example 4-2</u> |
|-----------------------|--------------------|--------------------|
| Condition (2C)        | 4.17               | 2.38               |
| Condition (3D)        |                    |                    |
| (Object-Side Lens)    | 2.32               | 2.11               |
| (Image-Side Lens)     | 1.17               | 1.50               |
| <u>Condition (4D)</u> | <u>3.50</u>        | <u>3.07</u>        |

Set out below are the values of conditions (2E), (3E) and (5E) in Examples 5-1 and 5-2.

|                       | <u>Example 5-1</u> | <u>Example 5-2</u> |
|-----------------------|--------------------|--------------------|
| Condition (2E)        | 3.63               | 3.26               |
| Condition (3E)        |                    |                    |
| (Object-Side Lens)    | 2.36               | 2.55               |
| (Image-Side Lens)     | 1.60               | 1.48               |
| <u>Condition (5E)</u> | <u>4.56</u>        | <u>4.01</u>        |

Set out below are the values of conditions (2F), (3F), (4F) and 5(F) in Examples 6-1, 6-2 and 6-3.



|                     | <u>Ex. 6-1</u> | <u>Ex. 6-2</u> | <u>Ex. 6-3</u> |
|---------------------|----------------|----------------|----------------|
| Condition (2F)      | 6.98           | 10.65          | 6.57           |
| Condition (3F)      |                |                |                |
| (Object-Side Lens)  | 1.94           | 1.59           | 2.50           |
| 5 (Image-Side Lens) | 1.28           | 1.39           | 1.17           |
| Condition (4F)      | 6.40           | 4.58           | 202.83         |
| Condition (5F)      | 3.62           | 4.10           | 4.03           |

Set out below are the values of conditions (2G),  
 10 (3G), (4G) and 5(G) in Examples 7-1, 7-2 and 7-3.

|                   | <u>Ex. 7-1</u> | <u>Ex. 7-2</u> | <u>Ex. 7-3</u> |
|-------------------|----------------|----------------|----------------|
| Condition (2G)    | 4.59           | 4.96           | 4.92           |
| Condition (3G)    | 3.62           | 3.72           | 3.97           |
| Condition (4G)    | 1.96           | 2.30           | 2.06           |
| 15 Condition (5G) | 3.15           | 3.12           | 3.81           |

By the way, although glass is used for all the  
 lenses in the zoom optical systems according to the above  
 example, it is acceptable to use a plastic material for  
 20 them. With the use of resinous materials for lenses, it  
 is possible to easily mass-fabricate them by molding  
 processes for the resinous materials. Expensive resinous  
 materials make it possible to achieve expensive optical  
 systems.

25 It is also acceptable to use organic-inorganic  
 composite materials in place of glass. Organic-inorganic  
 composite materials usable herein are now explained.

In an organic-inorganic composite material, an

organic component and an inorganic component are mixed together into a composite material at a molecular level or a nano-scale. Some available forms include (1) a structure wherein a polymeric matrix comprising an organic skeleton and a matrix comprising an inorganic skeleton are entangled together and penetrated into each other, (2) a structure wherein inorganic fine particles (so-called nano-particles) much smaller than the wavelength of light on a nano-scale are uniformly dispersed throughout a polymeric matrix comprising an organic skeleton, and (3) a combined structure of both.

Between the organic component and the inorganic component there are some interactions such as intermolecular forces, e.g., hydrogen bonds, dispersion forces and Coulomb force, attractive forces resulting from covalent bonds, ionic bonds and interaction of  $\pi$  electron clouds, etc. In the organic-inorganic composite material, the organic component and the inorganic component are mixed together at a molecular level or at a scale level smaller than the wavelength of light. For this reason, that composite material provides a transparent material because of having little or no influence on light scattering. As can also be derived from Maxwell equation, the composite material possesses the optical characteristics of each of the organic and inorganic components. Therefore, the organic-inorganic composite material can have various optical properties (such as

refractive index and chromatic dispersion) depending on the type and quantitative ratio of the organic and inorganic components present. Thus, it is possible to obtain various optical properties by blending together the organic and inorganic components at any desired ratio.

Some exemplary compositions of an organic-inorganic composite material comprising an acrylate resin (of the ultraviolet curable type) and nano-particles of zirconia ( $ZrO_2$ ) are shown in Table 1; some exemplary compositions of an organic-inorganic composite material comprising an acrylate resin and nano-particles of zirconia ( $ZrO_2$ )/alumina ( $Al_2O_3$ ) in Table 2; some exemplary compositions of an organic-inorganic composite material comprising an acrylate resin and nano-particles of niobium oxide ( $Nb_2O_5$ ) in Table 3; and some exemplary compositions of an acrylate resin and nano-particles of zirconium alkoxide/alumina ( $Al_2O_3$ ) in Table 4.

Table 1

Zirconia

| Content          | $n_d$    | $v_d$    | $n_c$    | $n_F$    | $n_g$    |
|------------------|----------|----------|----------|----------|----------|
| 0 (100% acrylic) | 1.49236  | 57.85664 | 1.48981  | 1.49832  | 1.50309  |
| 0.1              | 1.579526 | 54.85037 | 1.57579  | 1.586355 | 1.59311  |
| 0.2              | 1.662128 | 53.223   | 1.657315 | 1.669756 | 1.678308 |
| 0.3              | 1.740814 | 52.27971 | 1.735014 | 1.749184 | 1.759385 |
| 0.4              | 1.816094 | 51.71726 | 1.809379 | 1.825159 | 1.836887 |
| 0.5              | 1.888376 | 51.3837  | 1.880807 | 1.898096 | 1.911249 |

Table 2

|    | $\text{Al}_2\text{O}_3^*$   | $\text{ZrO}_2^*$ | $n_d$    | $v_d$    | $n_c$    | $n_F$    | $n_g$     | Remarks      |
|----|---|------------------|----------|----------|----------|----------|-----------|--------------|
|    | 0.1   | 0.4              | 1.831515 | 53.56672 | 1.824581 | 1.840374 | 1.8151956 | 50% acrylate |
| 5  | 0.2   | 0.3              | 1.772832 | 56.58516 | 1.767125 | 1.780783 | 1.790701  |              |
|    | 0.3   | 0.2              | 1.712138 | 60.97687 | 1.707449 | 1.719127 | 1.727275  |              |
|    | 0.4   | 0.1              | 1.649213 | 67.85669 | 1.645609 | 1.655177 | 1.661429  |              |
|    | 0.2   | 0.2              | 1.695632 | 58.32581 | 1.690903 | 1.702829 | 1.774891  |              |
|    | $\text{Al}_2\text{O}_3^*$ : quantitative ratio of $\text{Al}_2\text{O}_3$ |                  |          |          |          |          |           |              |
| 10 | $\text{ZrO}_2^*$ : quantitative ratio of $\text{ZrO}_2$                   |                  |          |          |          |          |           |              |

Table 3

|   | $\text{Nb}_2\text{O}_5^*$ | $\text{Al}_2\text{O}_3^*$ | $n_d$    | $v_d$    | $n_c$    | $n_F$    | $n_g$    |
|---|---------------------------|---------------------------|----------|----------|----------|----------|----------|
|   | 0.1                       | 0                         | 1.589861 | 29.55772 | 1.584508 | 1.604464 | 1.617565 |
|   | 0.2                       | 0                         | 1.681719 | 22.6091  | 1.673857 | 1.70401  | 1.724457 |
| 5 | 0.3                       | 0                         | 1.768813 | 19.52321 | 1.758673 | 1.798053 | 1.8251   |
|   | 0.4                       | 0                         | 1.851815 | 17.80818 | 1.839538 | 1.887415 | 1.920475 |
|   | 0.5                       | 0                         | 1.931253 | 16.73291 | 1.91708  | 1.972734 | 2.011334 |

$\text{Nb}_2\text{O}_5^*$ : content of  $\text{Nb}_2\text{O}_5$

$\text{Al}_2\text{O}_3^*$ : content of  $\text{Al}_2\text{O}_3$

10

Table 4

|    | $\text{Al}_2\text{O}_3^*$ | $\text{ZA}^*$ | $n_d$    | $v_d$    | $n_c$    | $n_F$    |
|----|---------------------------|---------------|----------|----------|----------|----------|
|    | 0                         | 0.2           | 1.533113 | 58.39837 | 1.530205 | 1.539334 |
|    | 0.1                       | 0.27          | 1.54737  | 62.10192 | 1.544525 | 1.553339 |
| 15 | 0.2                       | 0.24          | 1.561498 | 66.01481 | 1.558713 | 1.567219 |
|    | 0.3                       | 0.21          | 1.575498 | 70.15415 | 1.572774 | 1.580977 |
|    | 0.4                       | 0.18          | 1.589376 | 74.53905 | 1.586709 | 1.159616 |

$\text{Al}_2\text{O}_3^*$ : content of  $\text{Al}_2\text{O}_3$  (film)

$\text{ZA}^*$ : zirconia alkoxide

20

Electronic systems comprising such zoom or image-formation optical systems as described above are now explained. Used for such electronic systems is a taking unit wherein an object image formed through the above zoom optical system is received by an image pickup device such as CCD for taking. The electronic systems, for instance, include digital cameras, video cameras, digital video

units, information processors such as personal computers and mobile computers, telephone sets in general and easy-to-carry cellular phones in particular and personal digital assistants, as set forth below.

5           Figs. 57, 58 and 59 are conceptual illustrations of a digital camera, in which the zoom optical system of the invention is incorporated as a taking optical system 41. Fig. 573 is a front perspective view of the appearance of a digital camera 40, and Fig. 58 is a rear perspective  
10 view of the same. Fig. 59 is a sectional view of the construction of the digital camera 40.

          In this embodiment, the digital camera 40 comprises a taking optical system 41, a finder optical system 43, a shutter 45, a flash 46, a liquid crystal monitor 47 and so  
15 on. The taking optical system 41 is located on a taking optical path 42, the finder optical system 43 is placed on a finder optical path 44 separate from the taking optical path 42, and the shutter 45 is disposed on an upper portion of the camera 40. As the user presses down the  
20 shutter 45, it causes taking to occur through a taking optical system 41, for instance, the zoom optical system of Example 1-1 of the first zoom optical system.

          An object image formed by the taking optical system 41 is formed on the image pickup plane of a CCD 49 via a  
25 plane-parallel plate P1 and a cover glass P2. The plane-parallel plate P1 is provided with an ultraviolet cut coating. The plane-parallel plate P1 could also have a

low-pass filter function. The object image received at  
CCD 49 is shown as an electronic image on the liquid  
crystal monitor 47 via processing means 51, which monitor  
is mounted on the back of the camera. This processing  
5 means 51 could be connected with recording means 52 to  
record therein taken electronic images.

It is noted that the recording means 52 could be  
provided separately from the processing means 51 or,  
alternatively, it could be a floppy disk, a memory card,  
10 an MO or the like. Otherwise, the recording means 52  
could be constructed in such a way as to implement  
electronic recording or writing. This camera could also  
be constructed in the form of a silver-halide camera using  
a silver-halide film in place of CCD 49.

15 Moreover, a finder objective optical system 53 is  
located on the finder optical path 44. An object image  
formed by that finder objective optical system 53 is  
formed on a field frame 57, which is attached to a Porro  
prism 55 that is an image-erecting member. In the rear of  
20 the Porro prism 55 there is located an eyepiece optical  
system 59 for guiding an erected image into the eyeball E  
of a viewer. Three cover members 50 are provided: two on  
the entrance sides of the taking optical system 41 and the  
finder objective optical system 53 and one on the exit  
25 side of the eyepiece optical system 59. While plane-  
parallel plates are herein used for the cover members 50,  
it is noted that lenses having power could also be used.

The thus constructed digital camera 40 is improved in terms of performance and size reductions, because the taking optical system 41 has high performance and is slimmed down.

5 Figs. 60, 61 and 62 are illustrative of a personal computer that is one example of the information processor in which the zoom optical system of the invention is used as an objective optical system. Fig. 60 is a front perspective view of a personal computer 300 in use with a  
10 cover put up, Fig. 61 is a side view of a taking optical system 303 in the personal computer 300, and Fig. 62 is a side view of the state of Fig. 60.

The personal computer 300 comprises a keyboard 301 that enables the operator to enter information from  
15 outside, a monitor 302 for presenting information to the operator and a taking optical system 303 for taking images of the operator himself or herself and surrounding images. In addition, the personal computer 300 comprises information processing means, recording means, etc.,  
20 although not shown.

Here the keyboard 301 is provided for the operator to enter information from the outside in the computer. The information processing means and recording means are not shown. The monitor 302 could be any one of a  
25 transmission type liquid crystal display device illuminated from its back surface by a backlight (not shown), a reflection type liquid crystal display device



designed to display images by reflection of light coming from the front, a CRT display or the like. The taking optical system 303 is provided for taking an image of the operator and surrounding images. While the taking optical  
5 system 303 is shown as being built in the right-upper portion of the monitor 302, it is understood that it is not limited thereto; it could be located somewhere around the monitor 302 or keyboard 301.

This taking optical system 303 comprises, on a  
10 taking optical path 304, an objective lens 112 comprising the (roughly sketched) zoom optical system of the invention and an image pickup device chip 162 for receiving an image. These are built in the personal computer 300.

15 Here, a plane-parallel plate group F such as an optical low-pass filter is additionally applied onto the image pickup device chip 162. That is, the image pickup device chip 162 and the plane-parallel plate group F are set up as an image pickup unit 160 that can be fitted into  
20 the rear end of the lens barrel 113 of the objective lens 112 in one-touch operation, so that alignment of the objective lens 112 with the image pickup device chip 162, and surface-to-surface space adjustment are dispensed with, leading to easy assembling. At the front end of the lens  
25 barrel 113, there is located a cover glass 114 for protection of the objective lens 112. It is here noted that the driving mechanisms for the zoom optical system in

the lens barrel 113 is not shown.

An object image received at the image pickup device chip 162 is entered via a terminal 166 in the processing means of the personal computer 300, and shown as an  
5 electronic image on the monitor 302. As an example, an image 305 taken of the operator is shown in Fig. 60. This image 305 could be transmitted to and shown on a personal computer on the other end via suitable processing means and the Internet or telephone line.

10 Figs. 63(a), 63(b) and 63(c) are illustrative in conception of a telephone set that is another example of the information processor in which the zoom optical system of the invention is built, especially a convenient-to-carry cellular phone. Fig. 63(a) and Fig. 63(b) are a  
15 front view and a side view of a cellular phone 400, respectively, and Fig. 63(c) is a sectional view of a taking optical system 405.

The cellular phone 400 comprises a microphone 401, a speaker 402, an input dial 403, a monitor 404, a taking  
20 optical system 405, an antenna 406, and processing means (not shown). Here the microphone 401 is to enter the voice of the operator as information in the cellular phone, and the speaker 402 is to produce the voice of the person on the other end. The input dial 403 includes a button by  
25 which the operator enters information in the cellular phone. The monitor 404 is to show the images taken of the operator per se or the person on the other end and

indicate information such as a telephone number. A liquid crystal display is used as the monitor 404. The antenna 406 is to transmit and receive communications waves. It is here noted that the components or their positions are  
5 not limited to those shown.

The taking optical system 405 is located on a taking optical path 407. That taking optical system 405 comprises an objective lens 112 comprising the (roughly sketched) zoom optical system of the invention and an  
10 image pickup device chip 162 for receiving an object image. These are built in the cellular phone 400.

Here, a plane-parallel plate group F such as an optical low-pass filter is additionally applied onto the image pickup device chip 162. That is, the image pickup  
15 device chip 162 and the plane-parallel plate group F are set up as an image pickup unit 160 that can be fitted into the rear end of the lens barrel 113 of the objective lens 112 in one-touch operation, so that alignment of the objective lens 112 with the image pickup device chip 162,  
20 and surface-to-surface space adjustment are dispensed with, leading to easy assembling. At the front end of the lens barrel 113, there is located a cover glass 114 for protection of the objective lens 112. It is noted that the driving mechanism for the zoom optical system in the  
25 lens barrel 113 is not shown.

An object image received at the image pickup device chip 162 is entered via a terminal 166 in processing means

(not shown), so that the object image can be displayed as an electronic image on the monitor 404. The processing means also includes a signal processing function for converting information about the object image received at the image pickup device chip 162 into transmittable signals, thereby sending the image to the person on the other end, so that the object image can be displayed on a monitor on the other end.

#### 10 POSSIBLE INDUSTRIAL APPLICATIONS

With the invention, an effective tradeoff can be offered between the cost reductions and the size reductions of a zoom optical system, and an electronic system relying on it, too, can be slimmed down at low costs.